SEWAGE WORKS JOURNAL

VOL. X MAY, 1938 No. 3

Special Articles

Oxygen Demand of Sludge—Baity

Illinois River Studies—Wisely and Klassen

Activated Carbon and Sludge Digestion—Flower

Sewer Rental Laws in Michigan—Sandenburgh

Open and Covered Sludge Beds—Carpenter

Textile Waste Disposal—Hedgepeth

OFFICIAL PUBLICATION OF THE
FEDERATION OF SEWAGE WORKS ASSOCIATIONS

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

OFFICERS

Chairman

C. A. EMERSON, JR., George B. Gascoigne and Associates, Woolworth Bldg., New York, N. Y.

Vice-Chairman

LINN H. ENSLOW, Editor "Water Works & Sewerage," 155 E. 44th St., New York, N. Y.

Secretary-Treasurer

H. E. MOSES, Chief Engineer, State Dept. of Health, Harrisburg, Pa.

Business Manager

WM. W. BUFFUM, General Manager, The Chemical Foundation, Inc., 654 Madison Ave., New York, N. Y.

Editor

F. W. MOHLMAN, Chief Chemist, The Sanitary District of Chicago, 910 So. Michigan Ave., Chicago, Ill.

Board of Control

CHARLES C. AGAR, Albany, N. Y.
H. G. BAITY, Chapel Hill, N. C.
T. G. BANKS, Oklahoma City, Okla.
JUAN B. BERRINO, Buenos Aires, Argentina
ALBERT E. BERRY, Toronto, Canada
E. B. BESSELIEVRE, Buenos Aires, Argentina
FRED J. BIELE, Huntington, N. Y.
EARNEST BOYCE, Lawrence, Kansas
JOHN H. BROOKS, Worcester, Mass.
WM. W. BUFFUM, New York, N. Y.
AUSTIN BURT, Ontario, Calif.
J. A. CAROLLO, Phoenix, Ariz.
JORGE CLAYPOLE, Buenos Aires, Argentina
J. B. CROLL, Surrey, England
H. J. DARCEY, Oklahoma City, Okla.
W. W. DEBERARD, Chicago, Ill.
V. M. EHLERS, Austin, Texas
C. A. EMERSON, JR., New York, N. Y.
L. H. ENSLOW, New York, N. Y.
J. L. FEREBEE, Milwaukee, Wis.
GILBERT R. FRITH, Atlanta, Ga.
JOHN H. GARNER, Wakefield, England
F. WELLINGTON GILCREAS, Albany, N. Y.
C. G. GILLESPIE, Berkeley, Calif.
HARRY R. HALL, Hyattsville, Md.
A. D. HAMLYN, London, England
M. D. HOLLIS, Bismarck, N. D.
NORMAN J. HOWARD, Toronto, Canada
CHARLES G. HYDE, Berkeley, Calif.
W. SCOTT JOHNSON, Jefferson City, Mo.
FRANK WOODBURY JONES, Cleveland, Ohio
DANA E. KEPNER, Denver, Colo.
R. E. KOON, Portland, Ore.
W. S. MAHLIE, Fort Worth, Texas
C. D. MCGUIRE, Columbus, Ohio
A. P. MILLER, New York, N. Y.
H. E. MOSES, Harrisburg, Pa.
H. A. OLSEN, Ann Arbor, Mich.
WM. J. ORCHARD, Newark, N. J.
L. C. OSBORN, Loveland, Colo.
WM. M. PIATT, Durham, N. C.
WILLEM RUDOLFS, New Brunswick, N. J.
JAMES R. RUMSEY, Buffalo, N. Y.
D. H. RUPP, Topeka, Kansas
A. J. SMALSHAF, Columbus, Ga.
RICHARD C. SMITH, Glen Ridge, N. J.
H. W. STREETER, Cincinnati, Ohio
E. C. SULLIVAN, Washington, D. C.
W. W. TOWNE, Pierre, S. D.
DARIO TRAVAINI, Phoenix, Ariz.
EARLE L. WATERMAN, Iowa City, Iowa
A. H. WIETERS, Des Moines, Iowa
ABEL WOLMAN, Baltimore, Md.

SEWAGE WORKS JOURNAL

REG. U. S. PAT. OFF.

A Bimonthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of sewage works.

Publication Office: Prince and Lemon Sts., Lancaster, Pa.

Editorial Office: 910 So. Michigan Ave., Chicago, Ill.

Subscription Price:

Members of Local Sewage Works Associations affiliated with the Federation, $1.50 per year.

Non-members: Total fee $3.00, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50 per year; other countries, $4.00 per year.

Foreign Subscriptions must be accompanied by International Money Order.

Single copies: United States, $1.00 each; Foreign, $1.25 each.

Manuscript may be sent to the Editor, F. W. Mohlman, 910 So. Michigan Ave., Chicago, Ill., for acceptance or rejection subject to the provisions of the Federation constitution.

Subscriptions, advertising copy and address changes should be sent to the Business Manager's Office at Lancaster, Pa., or at 654 Madison Ave., New York, N. Y.

No claims will be allowed for copies of Journals lost in the mails unless such claims are received within sixty (60) days of the date of issue and no claims will be allowed for issues lost as a result of insufficient notice of change of address. "Missing from files" cannot be accepted as the reason for honoring a claim.

Entered as second-class matter, May 7, 1934, at the post office at Lancaster, Pa., under the Act of March 3, 1879.

Iowa City Sewage Plant. Consultants: Currie Engineering Co., Webster City, Iowa.

gives

CLEAR OVERFLOW
0.20% total solids · 330 P.P.M. suspended solids

LOW MOISTURE SLUDGE
87.1% Moisture

HIGH GAS PRODUCTION
1.05 cu. ft./capita/day

AT Iowa City, the Multdigestion System consists of a heated primary digester 40′ in dia. x 26′–10″ S.W.D., and an unheated secondary digester 60′ in dia. x 25′ S.W.D. It is digesting mixed primary and trickling filter sludge. The operating data below—from actual plant records for a six months' period—is published through the courtesy of Mr. J. F. Sproatt, Plant Superintendent.

IOWA CITY OPERATING DATA
(July through December 1937, inclusive)

Contributing population (estimated)	22,000
Raw Sewage Flow—m.g.d.	1.61
Raw Sludge to Digesters:	
Dry Solids—lbs. per day	3,240
Dry Solids—%	5.75
Volatile Matter—%	62.2
Digested Sludge:	
Solids—%	12.93
Volatile Matter—%	38.3
Solids Reduction—%	38.8
Volatile Matter Reduction—%	62.3
Digester Supernatant Liquor:	
Total Solids—%	0.20
Suspended Solids—p.p.m.	330
Gas Production:	
Average daily—cu. ft.	23,170
Cu. ft. per capita per day	1.05

Today 43 Dorr Multdigestion Systems are in use or on order. They all consist of a heated and mechanically stirred primary tank and an unheated secondary with an integral gas holder, supported by the gas. This arrangement assures a more completely digested sludge, greater gas production and a clearer supernatant.

A note to our nearest office will bring further details.

DORRCO

THE DORR COMPANY, INC. • ENGINEERS
570 LEXINGTON AVE. • NEW YORK
ATLANTA · TORONTO · CHICAGO · DENVER · LOS ANGELES

70 YEARS OF LEADERSHIP

Since 1868

Have Established

Features - Value - Prestige

Manufacturers and Equipment Engineers of

WATER WORKS AND SEWAGE WORKS EQUIPMENT

Mechanical Aerators—Diffused Air Type
Motor Driven Rotary Distributors
Reaction Driven Rotary Distributors
Sludge Collecting Mechanisms
Sludge Pumps—Comminuting Type
Sewage Pumps—Non-clogging Type
Double Suction Centrifugal Pumps
Deep Well Turbines

Our Sanitary and Hydraulic Engineering Staff is available to serve you on all phases of your requirements.

THE AMERICAN WELL WORKS

General Office and Plant

AURORA, ILLINOIS

Branches in all principal cities

LINK-BELT

STRAIGHTLINE EQUIPMENT

For Positive Results and High Efficiency

SCUM BREAKERS FOR DIGESTION TANKS
(ROUND OR RECTANGULAR)

•

BAR SCREENS

•

GRIT CHAMBER EQUIPMENT

•

STRAIGHTLINE COLLECTORS
(For rectangular tanks)

•

CIRCULINE COLLECTORS
(For center-feed round tanks)

•

MIXING EQUIPMENT
(ROTARY AND AIR)

•

FINE SCREENS

•

VARIABLE SPEED DRIVES
FOR PUMPS

Send for Catalogs *Address Nearest Office*

LINK-BELT COMPANY

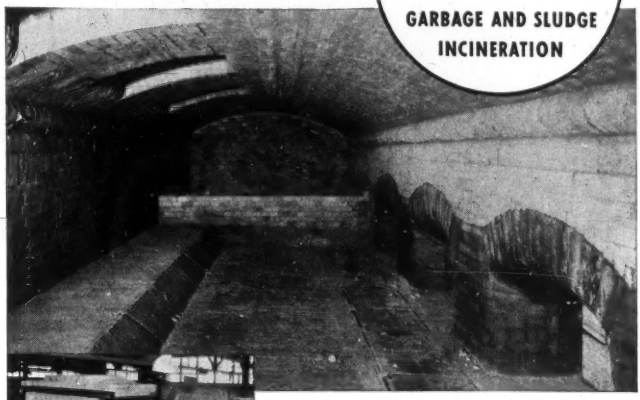
Philadelphia Chicago Indianapolis Los Angeles Toronto
Offices in Principal Cities

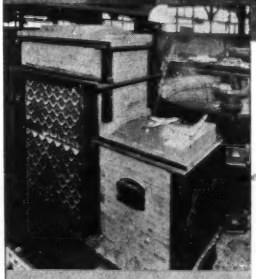
5977-B

"CARBOFRAX" GIVES YOU

REG. U. S. PAT. OFF.

LOWERED OPERATING COSTS • FAR GREATER EFFICIENCY IN GARBAGE AND SLUDGE INCINERATION





"CARBOFRAX"
REG. U. S. PAT. OFF.
The Carborundum Brand Silicon Carbide Refractory

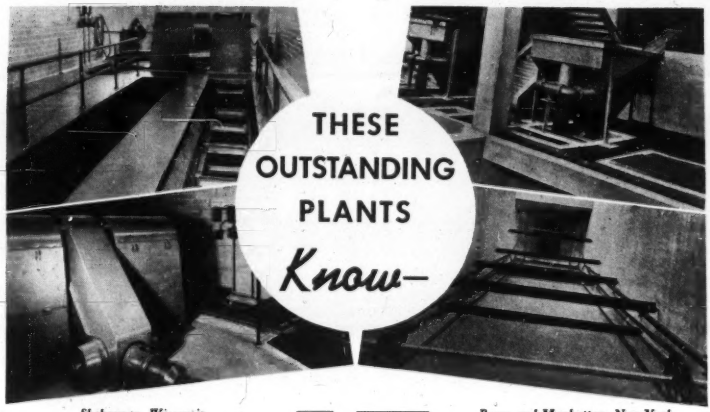
"CARBOFRAX" Brick for linings, piers and arches, "Carbofrax" Hearths and special shapes give long and uninterrupted service at high temperatures. No shutdowns because of lining failures due to softening or spalling.

The Carborundum Company Recuperator

For maximum efficiency in any sludge incinerator the pre-heating of air for combustion is essential. It will pay you to investigate The Carborundum Company Recuperator equipped with "Carbofrax" Tubes. Please write for detailed information.

THE CARBORUNDUM COMPANY
REG. U. S. PAT. OFF.
Refractory Division, Perth Amboy, N. J.

District Sales Branches: Boston, Chicago, Cleveland, Detroit, Philadelphia, Pittsburgh. Agents: L. F. McConnell, Birmingham, Ala.; Christy Firebrick Company, St. Louis; Harrison & Company, Salt Lake City, Utah; Pacific Abrasive Supply Co., Los Angeles, San Francisco, Seattle; Denver Fireclay Co., El Paso, Texas. (Carborundum and Carbofrax are registered trade-marks of The Carborundum Company.)



Sheboygan, Wisconsin
Grit Chamber and Washer

Bronx and Manhattan, New York
Grit Chambers

HOW TO HANDLE IT IF *IT* IS *GRIT*

They Are Using Rex Grit Collectors and Washers!

Rex Grit Collectors and Washers are installed all over the country in both large and small sewage plants. They bring new efficiency — low operating and upkeep costs to the job of collecting detritus and washing it to render it suitable for easy disposal. Write for complete information. Sanitation Equipment Division, Chain Belt Company, 1606 W. Bruce St., Milwaukee, Wis.

REX GRIT COLLECTORS AND WASHERS

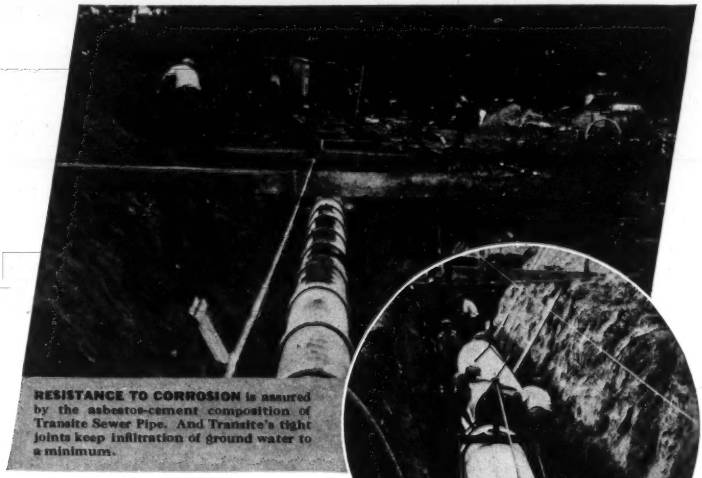
CONTRACTS AND INSTALLATIONS

Hartford, Connecticut	(4 units)
District of Columbia Blue Plaines Plant	(8 units)
*Madison, Wisconsin	
*Oklahoma City, Oklahoma	(2 units)
*New York, New York Bronx Plant	(2 units)
*New York, New York Manhattan Plant	(4 units)
*Atlanta, Georgia Entrenchment Creek Plant	(2 units)
Lincoln, Illinois	
*La Porte, Indiana	(1 unit)
*Atlanta, Georgia R. M. Clayton Plant	(1 unit) (2 units)
*Atlanta, Georgia South River Plant	(2 units)
Atlanta, Georgia Utoy Creek Plant	(1 unit)
*Sheboygan, Wisconsin	
*Racine, Wisconsin	(2 units)
*Buffalo, New York	(2 units)
Wellsville, New York	(6 units)
	(1 unit)

*Separate Rex Grit Washer

REX CHAIN BELT COMPANY of MILWAUKEE
Sanitation Equipment

The LAST WORD in sewer-pipe efficiency



RESISTANCE TO CORROSION is assured by the asbestos-cement composition of Transite Sewer Pipe. And Transite's tight joints keep infiltration of ground water to a minimum.

NOW you can install a really modern pipe in sewerage systems—Transite Sewer Pipe. Made of asbestos and cement, this J-M material offers savings and service never before available in the sewage-disposal field!

It is strong and durable, yet light in weight. That makes it economical to transport and handle. The 13-foot sections mean fewer joints at installation, saving money at the start. Moreover, these long lengths enable you to lay the pipe to exact grades with greater speed and accuracy.

Once installation is complete, maintenance expense is practically eliminated. Transite's asbestos-cement composition assures high resistance to both internal and external corrosion. And the tight joints employed minimize infiltration in the line. For complete details on this modern sewer pipe, write Johns-Manville, 22 E. 40th St., New York, N. Y.

LONG, 13-FOOT LENGTHS make laying to exact grades a more accurate, and a quicker and cheaper job with Transite Sewer Pipe. On force mains, too, these long lengths reduce installation costs.

JM Johns-Manville

TRANSITE SEWER PIPE AN ASBESTOS PRODUCT

Automatic Magnetite Filters

Improve Primary, Chemically Precipitated Activated Sludge and Trickling Filter Effluents.

ECONOMICAL TO BUILD AND OPERATE

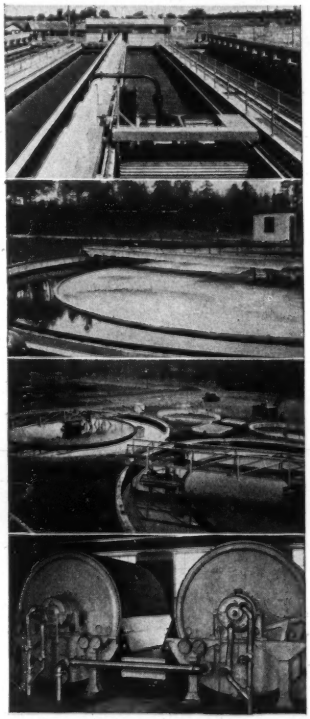
For Sludge Disposal Conkey Rotary Vacuum Filters are the Choice of Modern Cities Establishing Records as Leaders in Sanitation

Denver, Colorado.
6—12′x200′ downflow Magnetite Filters now in operation for straining both plain settled and chemically treated effluent.
Consulting Engineers, Black and Veatch, Kansas City.

Atlanta, Georgia, Intrenchment Creek Plant.
12′ upflow Magnetite Filter now in operation on 100′ diameter tank for filtering effluent from trickling filter.
Consulting Engineers, Wiedeman and Singleton, Atlanta.

Elmira, New York.
2—8′ wide upflow Magnetite Filters in operation on 60′ diameter tanks for straining plain settled and chemically precipitated effluent.
Consulting Engineers, Remington and Goff, Camden, N. J.

Neenah-Menasha, Wisconsin.
2 Conkey Rotary Vacuum Filters now operating for dewatering plain settled or digested sludge from domestic and paper mill wastes.
Consulting Engineers, Greeley and Hansen, Chicago, Ill.



For Complete Engineering Data Write to

FILTRATION EQUIPMENT CORP.

10 East 40th St. *Sales Office* New York, N. Y.

COARSE SCREENS · AUTOMATIC MAGNETITE FILTERS · CONKEY VACUUM FILTERS

BEREA, OHIO
Dresser flexible Couplings were used to provide pressure tightness, and permitted easier conformity of pipe to topography, on this three-line inverted siphon carrying sewage across deep gorge. The three lines (6", 8", 12") were laid in trenches excavated in precipitous rock banks. Consulting Engineer: Rollin E. MacDowell (Cleveland). Contractor: The Phillips Construction Co. (Cleveland).
PUZZLED
about joints for that new sewage line?
. . . write Dresser!
Every sewage-line project—whether raw-sewage, sludge, outfall, air, water-supply, or even inside piping—brings up special problems of tightness, ease of joint-making, type of labor, strength, permanence, costs, etc. In solving these problems, the modern trend is to Dresser Couplings. They give you the combined advantages of Permanent Tightness, Flexibility, Simplicity, Speed, Strength, and True Economy . . .
SEND TODAY for our general catalog No. 36 . . . a handbook of pipe-line construction!
DRESSER
Dresser Catalog No. 36
DRESSER
PIPE COUPLINGS
FOLLOWER (STEEL)
TRACK HEAD BOLT AND NUT (STEEL)
ROLLED THREADS
MIDDLE RING (STEEL)
RUBBER GASKET
PIPE STOP
PLAIN END PIPE
Cross section of Dresser Steel Coupling, Style 38, showing how it joins plain-end pipe in a flexible but permanently tight connection. Sizes available: 3/4" I.D. to the largest pipe produced.
S. R. DRESSER MFG. COMPANY, BRADFORD, PA. New York: 230 Park Ave.; Chicago: Peoples Gas Bldg.; Houston: Shell Bldg.; San Francisco: 1038 Folk St.; In Canada: Dresser Mfg. Co., Ltd., 60 Front St., W., Toronto, Ont.

NOTHING TAKES THE PLACE OF
WATER

NOTHING TAKES THE PLACE OF
CAST IRON PIPE

WATER is indispensable to human existence—cast iron pipe is indispensable to long life and economy in an underground main—nothing takes their place. Great progress has been made in the purification and distribution of water supply, as well as in the manufacture of cast iron pipe.

If you demand *proved* long life and low maintenance cost that result from effective resistance to corrosion—assured safety margins for impact, beam load and crushing stresses—and permanently tight joints—then you will agree that *nothing takes the place of cast iron pipe.* Some materials meet some of these requirements but only cast iron pipe meets them all.

Look for the "Q-Check" registered trade mark.
Cast iron pipe is made in diameters from 1¼ to 84 inches.

CAST IRON PIPE
THE STANDARD MATERIAL FOR UNDERGROUND MAINS

Sewage Works Journal

Published by

Federation of Sewage Works Associations

Lancaster, Pa.

Copyright, 1938, by Federation of Sewage Works Associations

Vol. X May, 1938 No. 3

Sewage Research:

Effects of Activated Carbon in the Digestion of Fresh Solids—Activated Sludge Mixtures. By G. E. Flower, Chester B. Budd and Charles Hauck 441

Chemical Coagulation of Sewage. IX. Order of Addition of Chemicals. By Willem Rudolfs and Harry W. Gehm 450

Studies on the Clarification Stage of the Activated Sludge Process. VIII. Uptake of Soluble Organic Substances. By Robert S. Ingols 458

Influence of Oxygen Concentration on B.O.D. By Richard Pomeroy. Discussion. By W. Rudolfs and H. Heukelekian. Closure. By Richard Pomeroy 465

Plant Operation:

Sewer Rental Laws in Michigan. By George H. Sandenburgh 482

Sludge Digestion and Inspection of Tanks at Rockville Centre, New York. By C. G. Andersen 494

Sludge Drying on Open and Covered Drying Beds. By Lewis V. Carpenter 503

Jackson, Michigan, Sewage Plant Operation. By R. B. Jackson and R. A. Greene. 513

Experiences and Results of First Year of Operation of the Ann Arbor Sewage Treatment Plant. By Harland P. Dodge 523

Industrial Wastes:

Textile Waste Disposal. An Orderly Approach to the Problem. By L. L. Hedgepeth and C. B. Griffin 534

Stream Pollution:

Some Factors Affecting the Aerobic Decomposition of Sewage Sludge Deposits. By H. G. Baity 539

The Pollution and Natural Purification of Illinois River Below Peoria. By W. T. Wisely and Clarence W. Klassen 569

Operators' Reports and Suggestions:

De Kalb Sanitary District, De Kalb, Illinois. By Donald E. Henn 596

The Mineola Sewage Treatment Plant. By Frank H. Hall 602

Rahway Valley, New Jersey, Joint Meeting Sewage Treatment Works. By Norman C. Wittwer 606

Editorial:

Oxygen Demand of Sludge Deposits 613

Proceedings of Local Associations:

Texas Water and Sewage Short School 615

Kansas Water and Sewage Works Association 618

Michigan Sewage Works Association 619

Federation Research Committee Report 620

Reviews and Abstracts:

Experimental Rapid Filtration at Huddersfield. By Dr. H. H. Goldthorpe 622
Multiple-Stage Sewage Sludge Digestion. By A. M. Rawn, A. Perry Banta and Richard Pomeroy 625
Discussion. By Willem Rudolfs and H. Heukelekian 630
The Design and Operation of the Coleshill Sewage-Disposal Works of the Birmingham, Tame and Rea District Drainage Board. By Frank Charles Vokes 631
Filter Pressing of Sludge. By J. T. Thompson and J. W. Procter 633
Stabilization of Sewage Sludge Banks. By Willem Rudolfs 636
Survey of the River Tees. Part III. The Non-Tidal Reaches—Chemical and Biological. By R. W. Butcher, J. Longwell and F. T. K. Pentelow 638

JOIN YOUR STATE OR LOCAL SEWAGE WORKS ASSOCIATION

AFFILIATE WITH THE NATIONAL FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Members of the Federation receive
THE SEWAGE WORKS JOURNAL
for $1.50 per year

Non-members' subscription fee $3.00 per year, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50; other countries, $4.00.

Send Subscriptions to
WM. W. BUFFUM, Business Manager
654 Madison Ave.
New York, N. Y.

Sewage Research

EFFECTS OF ACTIVATED CARBON IN THE DIGESTION OF FRESH SOLIDS-ACTIVATED SLUDGE MIXTURES

By G. E. Flower, Chester B. Budd and Charles Hauck

Superintendent, Sewage Plant Operator and Chemist, Southerly Sewage Treatment Plant, Cleveland, Ohio

Interest in the applications of activated carbon to sewage treatment is rapidly growing. There is recorded in the literature the experience of some twelve plants with activated carbon in sewage treatment and disposal. A brief summary of these reported experiences follows. A number of the plants, such as those at Rochester, N. Y., and Medina, Ohio, found activated carbon effective in reducing odors. Three plants reported improved digestion in unheated digestion tanks. Other plants experienced an acceleration of, and increase in, gas production. Activated carbon has also been useful in the elimination of scum nuisances and in grease removal from primary tanks. Drainability on sand beds and filtrability on mechanical filters were enhanced at several plants. Improvement of sedimentation in the primary tanks, the correction of bulking sludge, and better performance of the humus tank are other reported benefits resulting from the use of activated carbon.

During the past five years the sewage treatment facilities of Cleveland, Ohio, have been vastly improved and greatly enlarged. The contributing metropolitan area is roughly divided into three sections: westerly, southerly and easterly. The sewage of each district is treated at the plant located in that district. The Easterly Plant is an activated sludge plant of 120 m.g.d. capacity equipped with comminutors, detritors, degreasing tanks, aeration tanks and final settling tanks. The primary and excess sludge from this plant will be pumped through a 13 mile pipe line to the Southerly Plant for further treatment and ultimate disposal. To enable the Southerly Plant to handle these solids, a large construction program was initiated and is now nearing completion. After concentration in conically shaped tanks, the sludge is to be digested in the world's largest heated digestion installation; namely, twelve hexagonal tanks having a combined capacity of 2,000,000 cubic feet. After digestion the sludge will be conditioned with ferric chloride and lime and partially dewatered on mechanical vacuum filters to a moisture content of about 75 per cent. This dewatered sludge will then be incinerated in four rabbled multi-hearth furnaces.

It was with the hope of throwing light on anticipated plant problems that experimentation with activated carbon (Nuchar) was undertaken. The carbon used was generously supplied by the Industrial

Chemical Sales Co., Division of the West Virginia Pulp and Paper Co., through Mr. R. N. Statham of their Cleveland office. The problems anticipated and investigated were the effect of activated carbon on: (1) Odor control and possible applications in the concentration tanks; (2) the digestion process as shown in gasification, pH control, and solids destruction; (3) the settleability of the digested sludge as well as filtrability, and some possible applications to mechanical-vacuum filtration; (4) the possibility of economizing on the dosages of ferric chloride and lime for sludge conditioning before filtration, through the use of activated carbon.

Experimental Apparatus

In order to duplicate actual plant operating conditions we composited, in a one-gallon bottle, 0.6 liter of fresh solids (7 to 9 per cent solids) and 3.2 liters of activated sludge (0.25 to 0.40 per cent solids) in order to give a mixture containing 1 to 2 per cent solids. To develop sufficient activated sludge for our needs, we built a tank (32 by 24 by 12 in.) out of galvanized iron. Two National Carbon Co. tube air diffusers were suspended in the tank 6 in. from either end and 4 in. from the bottom. Compressed air was delivered to the diffusers, through

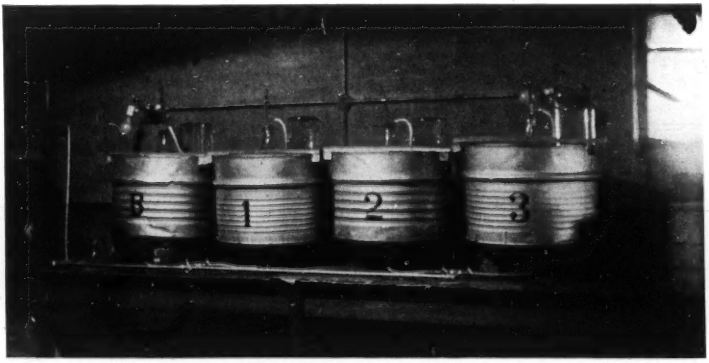


Fig. 1.—Experiments on the digestion of sewage solids with activated carbon.

rubber tubing, from a home-made compressor. To give the sludge the agitation it will get on its 10-hour journey through 13 miles of pipe from the Easterly Plant to the Southerly Plant, the samples were placed in a shaker and agitated for 10 hours. For digesters, four 19 liter carboys, pictured in Fig. 1, were employed. The carboys were set in heating tanks made from oil drums. These tanks were filled with water and heated with gas burners to a temperature between 30 and 35 degrees Centigrade. A glass tube extending within 2 in. of the bottom served as a sludge inlet line. Another tube which extended only 4 or 5 in. below the stopper served as a gas takeoff line. Inverted gal-

lon bottles acted as gas holders. To determine the sludge filtrability after digestion the apparatus shown in Fig. 2 was used. A Buchner funnel was tightly fitted into a two-hole rubber stopper, which in turn

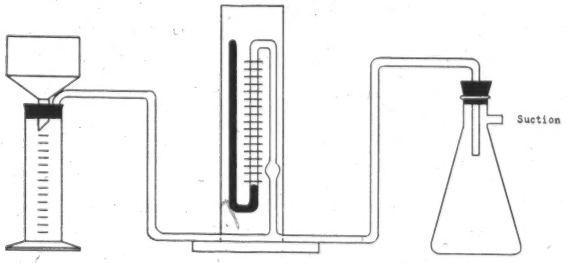


FIG. 2.—Setup for vacuum filtration of sludge samples.

was securely fitted into a sawed-off 500 ml. graduate. Through the other hole was drawn a quarter-inch glass suction line which was connected to a vacuum gauge. To eliminate the surge from the aspirator the manometer was attached to a suction flask.

EXPERIMENTAL ROUTINE

The composite of sludges was well mixed and divided into four aliquot portions of 800 ml. each, the remainder being used for laboratory analysis. The four samples were then known as B (blank or control), Number 1 (containing 0.16 gm. or 200 p.p.m. of Nuchar), Number 2 (containing 0.32 gm. or 400 p.p.m. of Nuchar), and Number 3 (containing 800 p.p.m. of Nuchar). The samples were exactly alike in all respects except for the varying dosages of Nuchar. The dosages of 200, 400 and 800 p.p.m. of Nuchar were based on the assumption that 1 per cent, by volume, of the raw sewage flow at the Easterly Plant would reach the Southerly Plant, carrying 1 to 2 per cent by weight of solids. Anticipating a raw sewage flow at the Easterly Plant of 100 m.g.d., and desiring a dosage in the raw sewage of 2, 4 and 8 p.p.m. it appeared logical to apply 200, 400 and 800 p.p.m. of carbon to the sludge. Actually not all of the carbon applied to the raw sewage would find its way to the settled sludge. It is important to keep in mind that the dosages of 200, 400 and 800 p.p.m. of carbon to the sludge samples are actually equivalent to only 2, 4 and 8 p.p.m. of carbon as applied to the raw sewage. It appears that carbon dosages to sewage would be more uniform if based on the per cent by weight of activated carbon added to the dry raw volatile solids present. Keefer and Kratz (6) used this basis for adding carbon to sludge in their experiments. After a 10 hour period of agitation the samples were taken from the shaking machine and brought to the laboratory for analysis. The data obtained are shown in Table I.

TABLE I

Sample	*B*	1	2	3
Carbon Dosages, p.p.m. on Solids Basis	0	200	400	800
Comparative Volumes Occupied by Sludge Solids After One Hour Settling Period	100	106	105	100
Comparative Volumes Occupied by Sludge Solids After Two Hour Settling Period	100	97	103	101
Total Suspended Solids in Supernatant After Two Hour Settling Period, p.p.m.	583	576	598	638
Volatile Suspended Solids in Supernatant After Two Hour Settling Period, p.p.m.	431	400	414	481
Description of Typical Odor	Obnoxious and very pronounced	Unpleasant and pronounced	Weak	Slight
Threshold Odor Values	80,000	26,000	20,000	16,000
Per Cent Odor Reduction	——	70	75	80
pH of Digested Sludge	6.8	6.9	6.8	6.9
Alkalinity of Digested Sludge, p.p.m.	1,430	1,780	1,450	1,430
Total Gas Volumes Produced, Comparative	100	147	115	117
C.c. of Gas Produced per Gram of Volatile Matter Destroyed	417	583	388	461
Max. Vacuum Reached in Filtering Digested Sludge, mm. of Mercury	707	725	712	702
Volume of Filtrate, After ¼ Minute, Without Ferric Chloride, Comparative	100	87	103	109
Volume of Filtrate After ¼ Minute, With Ferric Chloride, Comparative	100	108	116	113

Comparative values are obtained by using the results for sample B as a hundred.

SETTLEABILITY

Experimental.—Five hundred milliliters of each sample were poured into 500 ml. graduates and allowed to settle. The volume occupied by the solids, after various time intervals, was noted. Following a 4 hour sedimentation period, comparable samples of supernatant were withdrawn from the graduates. The suspended and volatile suspended solids were then determined on these samples.

Results.—In considering the effects of Nuchar on settling tendencies of the sludge, it was important to determine the solids load in the supernatant as well as the comparative volumes occupied by the settled sludge solids. On five occasions we had a rising sludge condition in our samples. In these instances carbon neither increased nor decreased the quantities of floating solids. The 200 p.p.m. dosage seemed to be the optimum for its effects on settling and the higher dosages apparently impeded settling and increased the solids load in the supernatant. In general, it may be said that any advantage or disadvantage to the settling qualities of the sludge appears within the limits of experimental error. It may also be noted that our observations on the effect of carbon upon the settleability of sewage sludges compare favorably with the results of Rudolfs and Trubnick (1).

Odor Control

Experimental.—On every sample, observations were made as to the character and strength of the sludge odors by shaking the sample well and recording the odor escaping at the mouth of the bottle. On several samples the observed odor differences were checked by means of the "threshold test" and also with Fair's Osmoscope.

Results.—In all cases the odor of the control sample B (no carbon) was substantially reduced, and noticeably improved by the lowest dosage of carbon employed. While the odor in B was very pronounced and obnoxious, the odor in Number 1 sample was unpleasant but not pronounced. The odor in Number 2 was weak and in Number 3 it was practically nil. To put it another way the 800 p.p.m. of carbon effected almost complete odor removal. By means of the "threshold test," as recommended by the American Water Works Association, we checked our routine odor observations. The percentage odor reductions cited in the table were measured by the "threshold test." Our experimentation with the Fair Osmoscope gave inconsistent results with the same sample in various dilutions. The results obtained by employing this instrument on a set of samples were not considered convincing. Odor reduction and control seems to be the outstanding merit of activated carbon in sewage treatment. The effect of a small amount of carbon on odor reduction and the proportionately less effects with much larger dosages is most interesting.

Digestion

Experimental.—Two to three hundred milliliters of each sample were used as charge into the digesters described above. The temperature of the water surrounding the carboys was maintained at 32° C. $\pm$ 2° C.

Results.—There appeared to be no appreciable or convincing effect on the hydrogen-ion concentration of the digested sludge, as determined by the Beckman pH meter. Rudolfs and Trubnick (1), however, found activated carbon tended to raise the pH of digested sludges due to the adsorption of carbon dioxide and the fatty acids. "Little or no change in the hydrogen-ion concentration of the digested sludge due to the addition of carbon" was reported by Walker (2). A marked effect on the pH of digested sludge was noted by Keefer and Kratz (6). They found that 4 per cent of carbon, on a dry volatile solids basis, raised the pH of the digested sludge from 6.3 to 6.7, while 8 per cent raised the pH from 6.3 to 6.9. The higher alkalinity of our sample Number 1 indicated better and more complete digestion. Both the rate of gas production and the volume yield were greater for the carbon treated samples in our experiments (Fig. 3). Walker (2) reports "While evidence is conflicting, the use of 5 to 15 p.p.m. of carbon on the raw sewage in sludge digestion at 20° C., appears to yield more gas, than is produced when no carbon is used; at 28° C., this same advantage does not appear. When added to the sludge in greater amounts the carbon appears to

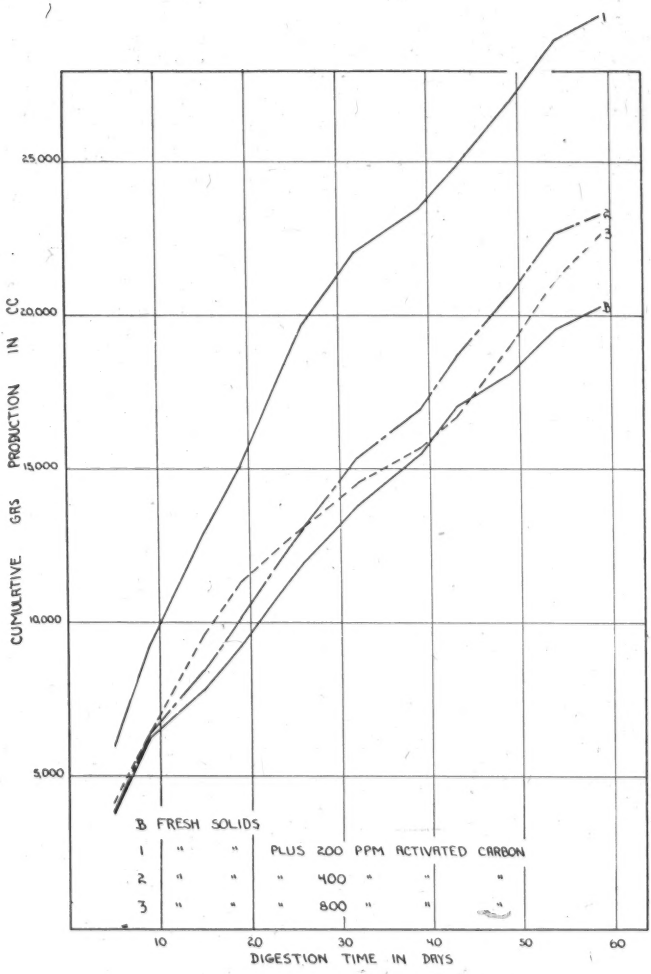


FIG. 3

reduce the amount of gas produced at all temperatures." Acceleration of the digestion processes and an improvement in quality and an increase in quantity of gas are reported by Keefer and Kratz (6). It appears certain from our experiments that activated carbon affects the liquid volumes of the digested sludge. To what extent and in what way

activated carbon causes these volume differences will be further investigated.

Filtrability

Experimental.—One hundred and fifty ml. samples were filtered through a Buchner funnel (see Fig. 2). Two sheets of C. S. and S. medium ashless filter paper were used as a mat.

Results.—A comparison of the relative volumes of filtrate after equivalent time intervals and at the same degree of vacuum indicated

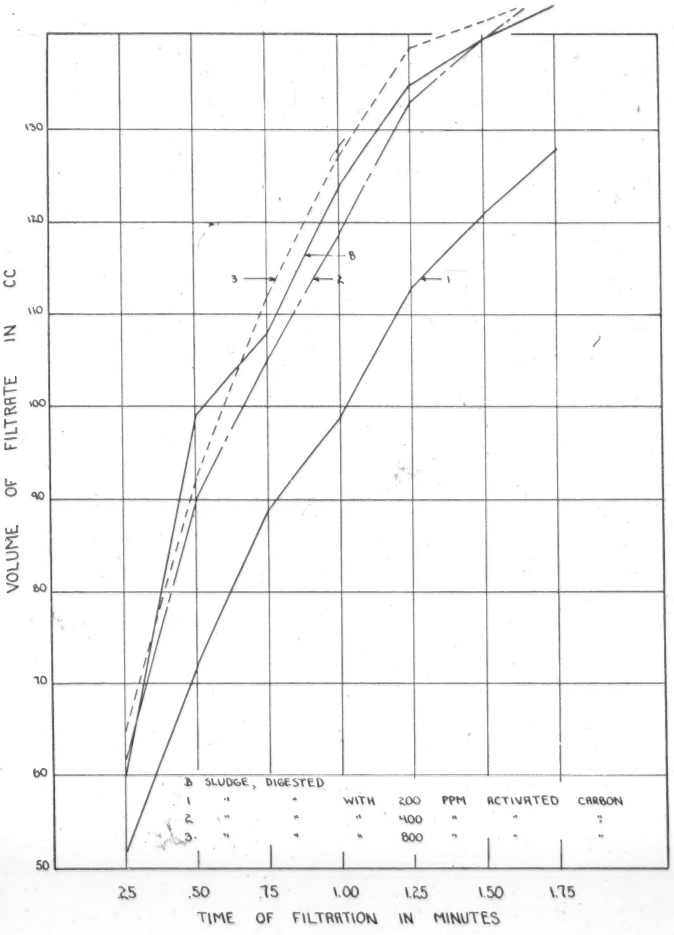


Fig. 4

that the higher dosages of carbon aided filtrability whether the sludge was treated with ferric chloride or not (Fig. 4). The comparative volumes after the first quarter minute are given in Table I. The relationships after each succeeding quarter-minute interval until the vacuum broke were virtually the same as after the first quarter minute. Another interesting point is that when treated with ferric chloride, 145 ml. of filtrate were obtained in 0.75 minute, as against a filtering time of 1.75 minutes to obtain the same volume of filtrate without ferric chloride. These facts indicate that possibly carbon would effect some worthwhile economy in conditioning chemicals required for sludge dewatering. Some plants report that carbon increases the rate of dewatering on sand beds.

Conclusions

In evaluating the various effects of carbon in sewage treatment one is immediately impressed with the difficulty of obtaining consistent results. Since 200 p.p.m. aids gasification one would expect 400 p.p.m. to aid it further. Such is not the case (Walker). Theoretically and experimentally (Rudolfs) activated carbon should tend to adsorb carbon dioxide and the fatty acids resulting from sludge digestion. Were this a fact, the pH of the various samples in our experiments would be progressively higher from B to Number 3. Our experience indicated that carbon had little effect on the pH of the digested sludges.

In the available reports of plant trials there are the same incongruities. Some plants find that activated carbon aids settling and sludge bulking and some do not. This lack of agreement among users and experimenters points, not to a lack of effect of carbon on sewage processes, but rather to an incomplete and inaccurate understanding of its rôle in these processes. Experimental studies in which all variables but one are controlled, and that one exhaustively investigated, is one avenue of approach to this problem. Another interesting aspect of carbon application in sewage treatment which needs clarification is the determination of the optimum dosage. There definitely appears to be a dosage below and above which the best results are not obtained. Of the dosages tried, 2, 4, and 8 p.p.m. (on a raw sewage basis) the 2 p.p.m. dosage was the optimum. The true optimum, however, may lie between 0 and 2 p.p.m. or between 2 and 4 p.p.m. There is no doubt about the value of carbon in odor reduction and control. Where odors are a problem activated carbon may be the solution. In those plants where it is desirable to reduce odors, the attendant benefits might justify the expense of carbon treatment. There is also some evidence to warrant using carbon to speed digestion and to accelerate and increase gas production. We feel that carbon may effect a saving in conditioning chemicals. This is a point that merits further study.

We wish to acknowledge the cooperation and assistance of J. W. Ellms, Commissioner of Sewage Disposal, City of Cleveland.

References

1. Rudolfs and Trubnick, *This Journal*, **5**, 852 (1935).
2. Walker, *Ibid.*, **2**, 207 (1937).
3. Scharch, *Municipal Sanitation*, 124, February, 1938.
4. Rogers, *This Journal*, **4**, 691 (1935).
5. Smith, *American City*, October, 1935.
6. Keefer and Kratz, *Water Works and Sewerage*, February, 1937.
7. Taste and Odor Control, Vol. 2, No. 10, June, 1936. Published by Industrial Chemical Sales Co.
8. Taste and Odor Control, Vol. 3, No. 7, March, 1937. Published by Industrial Chemical Sales Co.

CHEMICAL COAGULATION OF SEWAGE*

IX. ORDER OF ADDITION OF CHEMICALS

By Willem Rudolfs and Harry W. Gehm

Chief and Assistant, Division Water and Sewage Research, New Brunswick, N. J.

In most of the modern processes of chemical treatment of sewage at least two chemicals are usually employed. One of these chemicals is used for so-called pH adjustment or aid for coagulation. The common practice of employing two chemicals has led to a difference of opinion concerning the order of addition of the coagulant and the "pH adjusting chemical." Some workers state that the "pH adjusting chemical" should be added first, while others feel that the coagulant must be followed by the adjusting chemical. Since the opinions are based upon observations made in practice and are substantiated by results obtained at different places, it is probable that both opinions are correct for the specific sewages treated. In order to throw light upon this phase of chemical coagulation processes an endeavor is made in this paper to link the character of the sewage with the order of addition of chemicals.

If the purpose of the adjusting chemical is what the name implies, namely, of bringing the pH values to a point where maximum activity of the coagulant is obtained, it would appear that the adjusting chemical should be added first. If the reverse order were practiced the coagulant might be spent or robbed of its activity before the desired pH value was reached. The diverse results obtained in the field with modern coagulation processes, together with the results presented earlier in this series of papers (1), and the fact that a certain degree of coagulation can be obtained with either lime or acid alone, would indicate that the term "pH adjusting chemical" for lime or acid used in sewage coagulation is a misnomer. These "pH adjusting chemicals" are decidedly active for coagulation with or without added coagulants and are in reality aiding the effect of the chemicals producing a more rapid, stronger or better floc. Perhaps the more important factors which limit the use of the "pH adjusting chemicals" for coagulating agents are the large quantity required—when used alone—and the difficulty in obtaining relatively complete clarification without using excessive quantities. It appears therefore, that such chemicals used in moderate amounts are better termed "coagulation aids" than pH adjusting chemicals. Another fact supporting this terminology is, that pH adjustment with an alkali such as sodium hydroxide does not aid clarification materially when used in place of lime for pH adjustment.

Materials and Methods

Sewages of diverse character were chosen for the experiments to determine (1) the order of addition of aids and coagulants, and (2)

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J. Division Water and Sewage Research.

the possible specificity of certain chemicals for different sewage substances. The sewages used included strong, average and weak, fresh and septic sewages and some containing mixed trade wastes. The various types of sewages were treated with ferric iron and acid, ferric iron and lime, aluminum sulfate plus acid and aluminum sulfate plus lime. In each instance varying quantities of aids and coagulants were employed and the order of addition was varied. The chemicals used were thoroughly mixed with the sewage on each addition and a flocculation time of thirty minutes allowed. The turbidity remaining after one hour of quiescent settling was used as an index of clarification. In general the procedures followed in this work were those described in other papers of this series, except where otherwise stated.

Results

The first series of experiments comprised the addition of varying dosages of ferric chloride with sufficient lime to raise the pH value to 9.0. The ferric chloride was added before and after the addition of lime. Four sewages, classified as fresh domestic, weak stale, strong stale, and sewage containing industrial wastes, were tested. The results obtained are graphically shown in Fig. 1. The quantities of iron salt added varied from 1 to 16 p.p.m. as Fe.

The fresh domestic sewage clarified slightly better (3 to 4 per cent) when lime was added first, over the entire range of iron salt dosage. For the sewage containing industrial wastes the effect was the same, except that the improvement due to prior addition of lime was somewhat more marked; the differences amounting to 4 to 7 per cent for different quantities of iron salt added.

The septic weak and strong sewages showed an advantage in adding the coagulant last, only in the upper ranges of turbidity removal (above 70 per cent), where coagulant additions were comparatively high. Differences as high as 16 per cent turbidity removal were observed. With lower iron salt dosage usually better clarification was obtained when the coagulant was added first to septic sewages. With lower coagulant dosages, added first, as much as 10 per cent increased clarification was obtained.

It is of considerable interest and some importance that in all cases a larger and more rapidly settling floc was formed when lime dosage preceded coagulant addition. This effect would undoubtedly be accentuated in large scale continuous flow operation.

Similar experiments were repeated with the same and corresponding sewages, but applying the acid and ferric iron. Sufficient sulfuric acid was used to lower the pH values to 4.0 and again the coagulant dosages varied. Again the order of addition of adjusting chemical and coagulant was reversed. As an illustration of the effect of reversing the order of addition the results obtained on the same fresh, weak, strong and industrial waste containing sewages previously shown are plotted in Fig. 2.

All sewages responded in similar manner to the acid-ferric iron treatment. Addition of coagulant first resulted in considerably higher removals of turbidity. The magnitude of the differences varied, however, increasing with the septicity of the sewage, and in general with increased coagulant dosage. The fresh domestic sewage and the

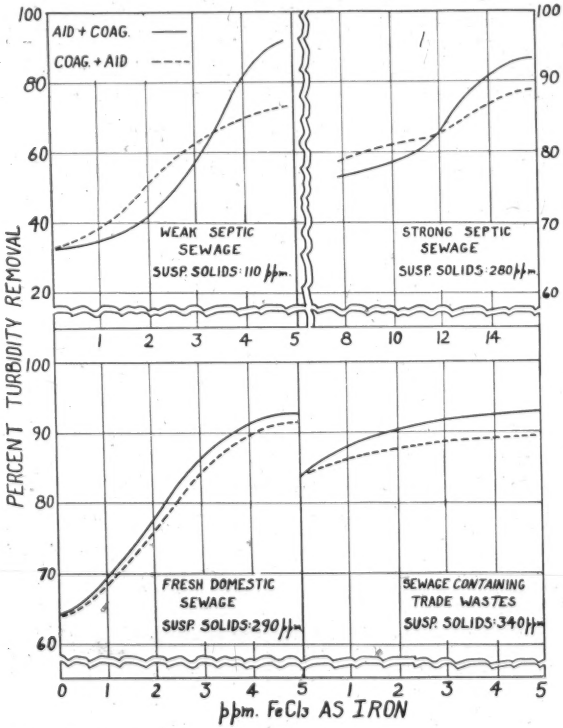


FIG. 1.—Effect of order of chemical addition, with increasing dosage, on turbidity removal in different types of sewages at pH 9.0.

strong sewage containing industrial wastes showed differences in clarification as much as 10 per cent, while the difference for the weak septic sewage amounted to 15 per cent and for the strong septic sewage over 20 per cent. The value of addition of the coagulant prior to the acid in any type of sewage appears to be well illustrated.

In order to obtain a general picture of the results that might be expected with the two methods of addition, four different sewages of varying strengths were treated with a constant ferric chloride dosage over a pH range of from 2.5 to 9.5. The ferric chloride dosage was kept

constant at 5 p.p.m. as Fe. The average results obtained are graphically shown in Fig. 3 as general curves of results to be expected.

Inspection of the curves indicate that in the pH range 4.5 to 8.0 little difference in order of addition of the chemicals is reflected in the resulting clarification, although a tendency exists to show slightly better results with coagulant addition before adjustment is practiced.

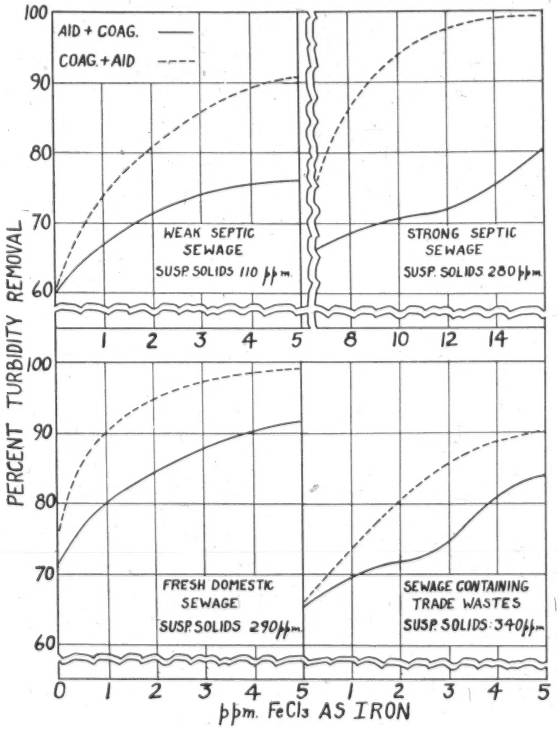


FIG. 2.—Effect of order of chemical addition at pH 4.0.

When sufficient acid was added to lower the pH values below 4.5 the turbidity remaining was lower when coagulant was added before the acid, corresponding to the greater removals (Fig. 2) when the iron dosage was varied and the amount of acid added was sufficient to lower the pH values to 4.0. Similar to the additional removals obtained with constant acid dosage the difference in clarification amounted to over 20 per cent.

In the pH range 8.0 to 9.5, when lime was used for adjustment, the

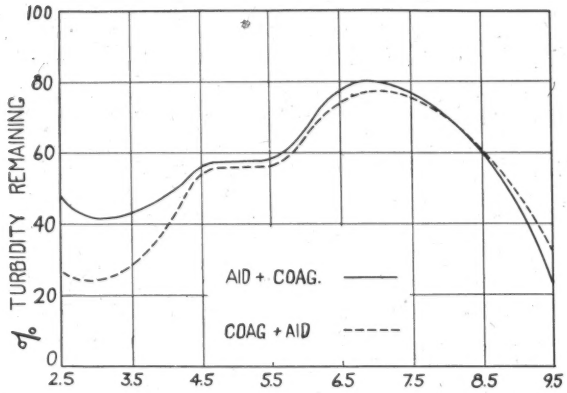


FIG. 3.—Effect of order of chemical addition, using ferric chloride, at pH 2.5 to 9.5.

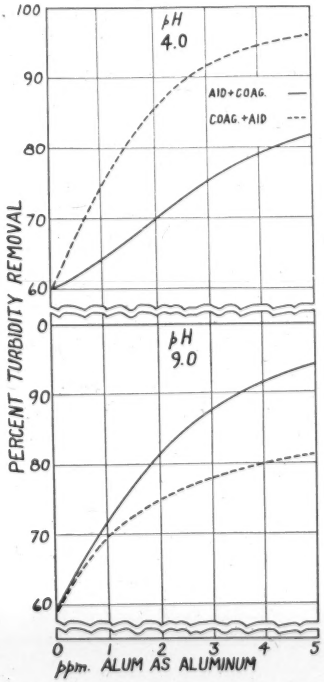


FIG. 4.—Effect of order of chemical addition, using alum, at pH 4.0 and 9.0.

addition of the coagulant after adjustment showed slightly better results. At the optimal point of clarification the removal of turbidity increased from 68 per cent with coagulant-adjustment to 75 per cent when the reverse order was practiced.

The general results obtained with ferric iron salt, and lime or acid as aids, brings up the question whether alum would behave the same under similar conditions with different types of sewages. A series of experiments were conducted with fresh, weak, strong and stale sewages and those containing industrial wastes by treatment with alum and sufficient lime to bring the pH values to 9.0 and with alum and sulfuric acid to change the pH values to 4.0. Again the results for individual sewages tested were so much in agreement that individual curves are not presented, but only two type curves constructed from the data obtained on all samples are given in Fig. 4. In most respects the alum coagulant in conjunction with aids behaved similarly to iron salts. It is clear that the addition of alum coagulant before adjustment is preferable when the pH value is lowered and the addition of an aid before the coagulant is added is better when the sewage is treated under alkaline conditions. The difference in clarification due to the order of addition was consistent and definite. The clarification obtained, when acid was added after the alum coagulant, became more noticeable with the increase in alum dosage. The increased turbidity removal amounted to as much as 15 per cent when coagulant was added first as compared with similar alum dosages after acid additions. When lime and alum were used the best removals were obtained by adding lime first, but the increase in turbidity removal was not as pronounced with lower alum dosages. For turbidity removals up to 80 per cent, only from 2 to 6 per cent increased removal was obtained when lime was added first, but when the alum dosage was increased to produce a turbidity removal of 90 per cent or more, the difference increased to 13 per cent in favor of lime-alum treatment as compared with the alum-lime treatment.

Discussion

The order of addition of lime and ferric coagulant showed no great differences in clarification with pH values up to 9.5 with any of the types of sewages treated. However, when lime was added first a more clean cut, larger and better settling floc was produced. The fact that the order of addition did not make much difference seems to indicate that lime acts as a coagulant as well as a "pH adjusting chemical." The behavior of the sewages when the lime was added first shows that its activity as a coagulant is more important than as an adjusting chemical. This would not necessarily be true if the iron salt remained in solution and the lime provided the needed alkalinity for hydrolization. But the latter is not the case, because the iron salt is either hydrolyzed by the alkalinity already present or combines with the organic matter in the sewage immediately upon addition. The lime produces a definite removal of turbidity when added and the total tur-

bidity removal is the sum of the removals by each chemical. It becomes therefore a question relationship between the two chemicals to obtain maximum results.

The better flocculation obtained by adding lime first is probably due mostly to physical action. The lime and its compounds are included in the floc caused by the iron coagulant to a greater extent when lime is added first than when the floc has been formed by the iron coagulant before lime has been added. This results in a heavier and better settling floc.

When acid is used with ferric salts all types of sewage treated experimentally clarified better when the iron salt was added first. The alkalinity present in the sewage is readily destroyed by the acid, allowing the iron coagulant to remain in solution until it combines with the sewage constituents, and preventing rapid hydrolysis, if any, of the iron salt, with subsequent better coagulation. The probability that some of the acid combines with certain sewage constituents, even when small quantities of acid are added, is indicated by the better results observed with fresh sewage as compared with septic sewages when the same quantities of acid are added first. The acid releases hydrogen sulfide from septic sewage and subsequent addition of iron coagulant precipitates the H_2S, resulting in loss of iron salt as coagulant. The loss of the coagulant is demonstrated by a lesser degree of activity or small turbidity removal. With larger quantities of acid, floc formation is fairly effective by the acid alone resulting in a reduction of coagulant to obtain the same turbidity removal. Here again, is the fact that the pH adjusting chemical acts more as a coagulant. The total clarification, as in the case of lime and ferric iron, is the sum of the turbidity removal obtained by the ferric chloride and the sulfuric acid when they are added in such a manner that one chemical was not detrimental to the action of the other.

From time to time evidence has been presented that a specificity of different chemicals for coagulation of certain substances appears to exist. The same has been found again in the studies under discussion and explains in part the failure of some coagulants to give complete coagulation even when added in excessive quantities to some sewages. It also explains in part the failure of certain single chemicals to coagulate properly during certain hours of the day when a domestic sewage is treated containing specific constituents, when larger quantities of laundry waste are present, or when amounts of specific trade wastes are suddenly discharged into the sewage. It has been found at several plants in New Jersey that it was necessary to supplement a single coagulant with lime or acid to meet at times certain conditions in the sewage which could not be handled with the single coagulant ordinarily used. The observations stated above are borne out by the general curve presented for fresh sewage. However, particular attention is called to the better flocculation with lime additions prior to coagulant, which is not evident from the curve. This

is of considerable practical importance in connection with settling facilities, and the chances are that addition of coagulant before lime may result in poorer clarification in large scale operation where unequal flow through a settling tank, insufficient detention time, or facilities for settling are not those desired.

The results showing that alum behaved much the same as ferric chloride are perhaps to be expected, but it seems of particular interest that alum clarification appeared to be consistent for different types of sewages. The results seem to indicate that alum produces results more predictable than ferric iron. It is probably because alum is less affected by the presence of reducing substances in the sewage. Rapidly acting ferric iron is more affected by the reducing substances present in stale or septic sewage, so that the removal or oxidation of these substances would result in more predictable and more uniform suspended solids removal. Part of these substances can be handled by pre-chlorination or short time aeration. It is better to keep the sewage fresh to prevent the entrance of additional factors which influence the activity of the coagulant. Under such conditions the results obtained become consistent with those theoretically expected. When alum and ferric iron coagulant are compared without lime or acid, the often light and fragile floc produced by alum should be taken into consideration.

Summary

In experiments on the order of addition of chemicals for sewage coagulation, lime and acid were used as coagulation aids and ferric iron and alum as coagulants. Fresh and septic, weak and strong sewages, and sewage containing trade wastes were used. The results indicate that when lime and ferric iron were used, best results were obtained when lime was added first. When acid and ferric iron were used, addition of coagulant before acid gave far better results. Attention is called to the denser and more rapidly settling floc when lime was added first. Alum produced results similar to ferric iron in respect to the order of addition. Different types of sewages responded more uniformly to alum than to ferric iron treatment. Lime and acid were found to function more as coagulating than pH adjusting chemicals and should be considereed as coagulation aids. A specificity of certain chemicals for different sewage substances was noted and the use of lime and acid as adjuncts to a coagulant, to meet certain transient conditions, was indicated.

Reference

1. W. Rudolfs and H. W. Gehm, *This Journal*, **8**, 195 (March, 1936).

STUDIES ON THE CLARIFICATION STAGE OF THE ACTIVATED SLUDGE PROCESS *

VIII. UPTAKE OF SOLUBLE ORGANIC SUBSTANCES

By Robert S. Ingols

Assistant, Division Water and Sewage Research, New Brunswick, N. J.

In the fifth article of this series (2) it was shown that the uptake of ammonia from sewage by activated sludge depends on biological activity. Since ammonia is only one of a group of soluble substances that may be found in sewage, the question arises whether ammonia can be shown to be a typical representative of these materials. The present study was conducted to evaluate the importance of the physical or biological factors which bring about the uptake of different soluble substances from solution. The soluble substances chosen include an hydrolysate of casein and glucose. The protein hydrolysate was chosen as a mixture of soluble organic nitrogenous compounds, which could be readily analyzed and which are ionogenic. The glucose was used as a representative labile carbon compound for which accurate methods of analysis are known. Glucose as such will probably not enter an aeration tank in large quantity, but it can be produced in the sewage from cellulose, starch, laundry wastes, garbage, etc. The mixture of amino acids in the protein hydrolysate has been studied at concentrations in excess of the amount expected in normal domestic sewage, but a certain concentration is required for analytical procedures. Packinghouse or tannery wastes would give the sewage a very much higher concentration of soluble organic nitrogenous material than that used in this study.

Methods

The methods used in this study are very similar to those used for the study of ammonia uptake (2). The possible adsorption or base exchange of the amino acids was studied with sludge prepared by treatment with 4.0 per cent NaCl, as described in the previous paper. A sample of 50 ml. of sludge (10,000 p.p.m. suspended solids) was centrifuged and the supernatant liquor discarded. The sludge was placed in 100 ml. of 4.0 per cent NaCl and stirred occasionally for a period of 20 minutes. The sludge was recovered by centrifuging and the supernatant was discarded. The excess salt in the sludge liquor was removed by alternately re-suspending the sludge in ammonia-free water and centrifuging the mixture, discarding the supernatant liquor. This sample of sludge was diluted to 200 ml. with ammonia-free liquor and after 40 minutes the supernatant liquor was filtered. This blank was run to determine the amount of sludge floc dispersion caused by the salt

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J. Division Water and Sewage Research.

treatment. Three other sludge samples were prepared with salt treatment, but were diluted with solutions of amino acids (protein hydrolysate) to 200 ml. to determine the amount of adsorption possible. The amino acids were left in contact with the sludge with occasional stirring for forty minutes. Equal volumes of paper filtrates were titrated for amino nitrogen by the Sörenson formol titration method as modified by Northrup (3).

The protein hydrolysate was prepared by refluxing a suspension of casein in 33 per cent sulfuric acid for 72 hours. The acid was removed by adding crystalline barium hydroxide until a pH was produced just below the isoelectric point of casein, to prevent the inclusion of any barium ions in the solution. The barium sulfate was filtered off and most of the color removed with activated carbon (Nuchar). The filtered solution was brought to pH 7.0 with sodium hydroxide giving a final concentration of 100 p.p.m. Na_2SO_4 in the final mixtures with the sludge.

The aeration experiments were conducted with approximately 1500 p.p.m. suspended solids of sludge. The effect of various amounts of sodium chloride on the uptake of both the amino acids and glucose was studied. Approximately 125 p.p.m. amino acids (25 p.p.m. amino nitrogen), and 200 p.p.m. glucose were added to each tube. The control was aerated without any sodium chloride. The other three tubes contained 4, 8, and 12 grams of sodium chloride per liter. The amount of amino nitrogen and glucose present initially and after 2 hours aeration was determined in each. (The amount of amino nitrogen is a direct indication of the amino acids present.)

In other aeration experiments the effect of glucose and chloroform on amino acid uptake was studied. In addition to the analyses for amino nitrogen and glucose the liquors were analyzed for ammonia at each sampling and nitrates at the completion of the experiments. Each sample was Seitz-filtered to remove all turbidity as each determination depended on colorimetry.

Results

The results of the study of adsorption of amino acids by activated sludge are shown in Table I. These figures indicate that the dispersion

Table I.—*Adsorption of Amino Acids (Expressed as P.P.M. Amino Nitrogen)*

Initial Concentration		Amino Nitrogen in Blank		Total Initially	Final Concentration After Contact	Adsorption
40.7	+	8.0	→	48.7	43.0	5.7
81.5	+	8.0	→	89.5	85.0	4.5
121.0	+	8.0	→	129.0	124.0	5.0

caused by the salt amounts to 8.0 p.p.m. amino nitrogen. This amounts to 20 per cent of the smallest quantity of amino acid nitrogen which was added to study adsorption. The 8.0 p.p.m. amino nitrogen in the blank

is greater than the amount of adsorption recorded in the last column, and the final concentration of amino nitrogen is greater than the initial. It is of importance that the possible amount of adsorption for each concentration of amino acids is practically constant, varying only between 4.5 and 5.7 and not showing any definite trend.

The effect of varying quantities of sodium chloride upon the uptake of amino acids and glucose by activated sludge is shown in Table II.

TABLE II.—*Effect of Sodium Chloride Upon the Uptake of Amino Acids and Glucose (Results in P.P.M. Remaining)*

Time of Aeration	Control		4 Grams NaCl		8 Grams NaCl		12 Grams NaCl	
	Amino Nitrogen	Glucose	Amino Nitrogen	Glucose	Amino Nitrogen	Glucose	Amino Nitrogen	Glucose
Initial.....	23.3	180	26.3	168	26.8	158	28.0	158
2 Hours.....	22.7	74	24.4	114	26.3	119	27.7	128
4 Hours.....	14.3	0	19.5	5	25.8	63	30.0	85

Four hours of aeration permitted the uptake of 9 p.p.m. of amino nitrogen and all of the glucose by the control which did not contain any sodium chloride. Four grams of salt retarded the uptake of the amino acids and glucose only slightly during the 4-hour period. Eight grams of salt practically blocked the uptake of amino nitrogen and markedly retarded the uptake of glucose. Twelve grams of salt not only blocked the uptake of amino nitrogen but also caused some dispersion of the floc and thus an increase in the amino nitrogen. The glucose utilization was further retarded but not completely blocked.

TABLE III.—*Effect of Glucose and Chloroform Upon the Uptake of Amino Acids by Activated Sludge*

Time	Amino Acid Only			Amino Acid +Glucose				Amino Acid +Glucose +Chloroform		
	NH_3-N	Amino-N	NO_3-N	NH_3-N	Amino-N	Glucose	NO_3-N	NH_3-N	Amino-N	Glucose
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
Initial.....	7.0	30.0	—	5.0	28.0	180	—	7.0	27.5	211
2 Hours.....	5.0	18.5	—	6.0	22.0	30	—	7.0	35.5	185
4 Hours.....	7.0	12.5	10.0	9.0	18.2	0	2.4	—	—	—

In Table III results are given, dealing with the effect of glucose and chloroform upon the uptake of amino acids by activated sludge. In the control tube the uptake of amino acids was quite rapid as indicated by the drop in amino nitrogen. The quantity of ammonia remained relatively constant. The amino nitrogen decreased 17.5 p.p.m. in 4 hours, while during this time 10 p.p.m. nitrate nitrogen was produced. This leaves a balance of 7.5 p.p.m. amino nitrogen. The sludge containing glucose showed an increase of 4 p.p.m. ammonia nitrogen, and a production of 2.4 p.p.m. nitrate nitrogen. Since a total of 9.8 p.p.m. amino

nitrogen was utilized and 6.4 p.p.m. nitrate and ammonia nitrogen produced, there was a balance of 3.4 p.p.m. amino nitrogen. The high rate of 150 p.p.m. glucose utilization occurred during the first two hours. The addition of chloroform caused a marked dispersion of the sludge floc and a definite increase in the amino nitrogen. However, the ammonia remained constant. There was a decrease of 26 p.p.m. glucose during the first two hours.

Discussion

To study the adsorption of ammonia by activated sludge the sludge was prepared either by electrodialysis or by washing with a solution of sodium chloride. Either method causes marked changes in the sludge so that the supernatant must be filtered, but this condition does not interfere with the adsorption of ammonia. This dispersed material, however, contained a large amount of amino nitrogen, which was more than the amount of amino nitrogen that could be apparently adsorbed by the sludge. This was true of the three concentrations of amino nitrogen (amino acids), studied. The same results were obtained with the amino acid, glycine, and therefore are not included. The laws of adsorption require that with an increasing concentration of substrate an increasing amount of the substrate at low concentration thereof be adsorbed on the adsorbent. These conditions were not fulfilled in this experiment. It must be concluded that either the sludge was not properly prepared or that the amino acids, although ionogenic, are not capable of being exchanged for the sodium chloride adsorbed on the sludge. Since a number of the amino acids from a protein hydrolysate are only slightly soluble at pH 7.0, these acids should be readily adsorbed if any adsorption were possible under the conditions of the experiment. The above results indicate that neither adsorption nor base exchange of amino acids by activated sludge takes place. For the purpose of clarifying the discussion it will be only necessary to indicate that the amino acids follow the laws of biological activity in their disappearance when aerated with activated sludge.

Before discussing the results of this study and comparing them with those reported for ammonia, a brief comparison of ammonia and amino acids is needed. There are at least twenty different amino acids that may be obtained by the complete hydrolysis of a protein. Protoplasm, which is basically protein, must therefore require amino acids to increase in quantity, *i.e.*, they are required for the growth of all organisms. Their use must be accompanied by the liberation of energy. The amino acids may be obtained from two sources (1) amino acids of other proteins which are obtained by hydrolysis (2) the synthesis from ammonia and some carbonaceous compound such as glucose or fat. When amino acids are present the latter reaction will not take place readily. The energy will be obtained in aerating activated sludge from the oxidation of (1) organic compounds: glucose, fats, amino acids; (2) inorganic compounds; ammonia and hydrogen sulfide. When the organic compounds are present the ammonia and hydrogen sulfide will

not be readily utilized. Of the organic compounds, the glucose will be most readily oxidized for the production of energy.

If only amino acids are present, organisms will remove the amino group of a portion of the acids either by hydrolysis or by oxidation and the de-aminized portion of the acids will be oxidized to carbon dioxide and water for energy. Other amino acids will be used for growth. The amino group will be discarded as ammonia, which will be utilized by special organisms for energy. These special organisms will oxidize the ammonia to nitrites and others will oxidize the nitrites to nitrates, but these reactions will not influence the uptake of amino acids although they will alter the ammonia uptake. If glucose is present to provide the energy, fewer of the amino acids will be broken down for energy and less ammonia will be produced.

When nitrogen is present as ammonia there must be a source of carbon for the synthesis of amino acids. It has been shown (2) that glucose caused a more rapid utilization of the ammonia, and it may be seen now why this was to be expected. There are marked differences between amino acids and ammonia: (1) amino acids may be utilized directly for building protoplasm, ammonia cannot; (2) amino acids may be oxidized by practically all organisms for energy, ammonia by only a specialized few; (3) amino acids can be broken down to produce ammonia, while ammonia must unite with carbon compounds to produce amino acids.

The results given in this paper fit very well these theoretical requirements. Glucose retarded the uptake of amino acids so that the total disappearance of amino nitrogen in the absence of glucose was 17.5 p.p.m. as against 9.8 p.p.m. in the presence of glucose. Of the 17.5 p.p.m. amino nitrogen used by the activated sludge 10 p.p.m. was converted to ammonia and then to nitrite or nitrate nitrogen. In the presence of glucose only 6.4 p.p.m. nitrogen was given off as ammonia. This amount was higher than anticipated in view of the large amount of glucose oxidized, but the differences are large enough to be significant.

In the presence of chloroform there was a constant amount of ammonia in the liquor; this checks the results of the previous paper (2). The chloroform not only checked the utilization of amino acids but it caused a sufficient liberation of protoplasm to increase the amino nitrogen. The partial antisepsis of the chloroform failed to check the disappearance of the glucose. Glucose also disappeared in the presence of 12 grams of sodium chloride, which prevented the uptake of ammonia and amino acids.

Can this disappearance of the glucose be due to physical adsorption? The author believes that this disappearance is due to enzymatic degradation of the glucose and to the use of very small amounts of glucose by a few hardy cells for their maintenance metabolism. The breakdown of the amino acids by this same mechanism is probably taking place, but the plasmolysis of the large number of cells, giving an increase in amino nitrogen, masks the breakdown of the amino acids.

If this explanation be true, destruction of the enzymes with heat should permit the maintenance of a constant sugar level. This explanation was verified by boiling a liter of activated sludge containing 1800 p.p.m. suspended solids and then adding 200 p.p.m. sterile glucose. A sample was drawn and Seitz filtered and analyzed for glucose. The boiled sludge was aerated for two hours and another sample was drawn and analyzed for glucose. The same quantity of glucose was found in each sample, showing that in the absence of all active biological processes glucose is left untouched by a boiled activated sludge floc.

Only very little is known of the mechanism of enzyme activity but this much is realized: enzyme activity depends upon the concentration of the substrate at the enzyme surface (by definition, adsorption). When it was stated above that the disappearance of the glucose was due to enzyme degradation, it was tacitly admitted that adsorption of the glucose had taken place. One of the primary principles of enzyme activity is the specificity of this activity. Maltose and cellobiose are both composed of two molecules of glucose yet maltase will not hydrolyse cellobiose and cellobiase will not hydrolyze maltose. Therefore, when it was stated that enzyme degradation was responsible for the disappearance of glucose, adsorption was admitted, but the adsorption was not upon any random surface of the sludge floc, but upon a specific, active surface of that floc. The amount of enzyme present is so small that it could hardly account for the adsorption of a reasonable amount of glucose at any one time. In the paper on the hydrolysis of starch (1) it was stated that no concentration of the starch color with iodine was found in the sludge floc and that the starch remained suspended in the liquor for some time. However, hydrolysis of the starch required the concentration of the starch at the enzyme surface, but again the adsorption was specific.

Ammonia did not disappear in the presence of chloroform or 12 grams of sodium chloride (2). Amino acid consumption dropped to almost nothing at 8 grams of sodium chloride per liter while the glucose consumption was higher than at 12 grams of salt per liter. In part, this difference is due to the fact that the growth mechanism of organisms is more sensitive, than is their maintenance mechanism, to slightly toxic conditions. When 4 grams of sodium chloride was used per liter there was a ready uptake of amino acids and glucose. These figures again show that ionized substances are readily removed by activated sludge even though there is a high concentration of other ionized materials present.

Summary

Studies on the relative importance of physical or biological processes in the removal of soluble materials by activated sludge are reported. The method used in preparing the sludge for the study of ammonia adsorption was ineffective in preparing the sludge for adsorption of an amino acid mixture.

The rates of disappearance of amino acids and glucose were correlated with known laws of bacterial physiology. The uptake of the

amino acids was demonstrated in concentrations of salt much greater than the amounts of amino acids used. The relative importance of various surfaces of the activated sludge floc as regards adsorption is discussed. Any adsorption of glucose is the property of specific surfaces of the sludge. These specific surfaces are known as enzymes.

The removal of soluble organic substances is brought about by biological or biochemical processes independently of purely physical phenomena. This checks the results with ammonia.

REFERENCES

1. H. Heukelekian and R. S. Ingols, "Studies on the Clarification State of the Activated Sludge Process. VI. Hydrolysis of Starch." *This Journal*, **10**, 209 (1938).
2. R. S. Ingols, "Studies on the Clarification Stage of the Activated Sludge Process. V. Ammonia Uptake." *This Journal*, **10**, 49 (1938).
3. J. H. Northrop, "A Convenient Method for the Formal Titration." *Jour. General Physiology*, **9**, 767 (1925–26).

INFLUENCE OF OXYGEN CONCENTRATION ON BIOCHEMICAL OXYGEN DEMAND

By Richard Pomeroy

Research Chemist, Los Angeles County Sanitation Districts

In the course of an extended investigation at this laboratory of the effect of dilution on the B.O.D. test, it has become necessary to know what effect oxygen concentration may have on the test. Comparatively little data are available in the literature showing B.O.D. values at various oxygen concentrations, *with all other conditions held constant.* Such data as have been published are not conclusive or entirely in agreement. The experimental investigation conducted in this laboratory has given conclusive evidence of a decrease of the rate of oxygen consumption with increasing oxygen concentration; this conclusion seems to be of sufficient importance to warrant the presentation of the results.

Experimental

Four types of sewage material were used for the B.O.D. determinations: (1) thoroughly settled raw sewage, (2) filtered raw sewage, (3) a partially oxidized effluent having a B.O.D. of about 60, and (4) filtered effluent of the foregoing type. All samples were taken from the treatment plant of the Los Angeles County Sanitation Districts. The filtered samples were in all cases seeded with a little of the unfiltered material. Filtered samples were found to be more satisfactory than those containing suspended solids, because the suspended solids settling from the unfiltered samples cause localized septic conditions in the bottoms of the incubation bottles. There is some settling of coagulated matter even from filtered samples.

In order to prepare a series of samples with all conditions constant except the oxygen concentration, the following procedure was used: A series of glass-stoppered bottles of 2½ liter capacity were partly filled with varying amounts of distilled water from which the oxygen had been removed by boiling, or which had been oxygenated by shaking with commercial tank oxygen. The amounts of de-aerated or oxygenated water required to give suitable final oxygen concentrations were found by experience. To each bottle there was added enough of the sewage, on the basis of the carefully determined volumes of the bottles, to give the same concentration in each bottle, and enough $NaHCO_3$ to give a concentration of 300 p.p.m. Finally the bottles were completely filled with distilled water of normal oxygen content. From each bottle eight 250-ml. bottles were filled by siphoning. Four of these were analyzed for initial oxygen concentration, and the other four were incubated in a constant-temperature water-bath and then analyzed. Thus each depletion was determined by quadruple initial and final determinations. The simple Winkler method was used for the oxygen

determinations, with these modifications: (1) 2 ml. of $MnSO_4$ solution were used for the higher oxygen concentrations, and (2) after the precipitate had settled, one ml. of a solution of 60 grams of KI in 100 ml. distilled water was added to each bottle. Burette readings were made to 0.01 ml. The thiosulfate solution was standardized each day.

TABLE I.—*Influence of Oxygen Concentration on 5-day B.O D*

Series I (Effluent)			Series II (Effluent)			Series III (Effluent)			Series IV (Filtered Raw Sewage)			Average	
D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	R.D.
1.8	0.92	108.1	1.6	1.16	118.5	1.5	0.68	111.1	2.2	0.62	101.3	1.8	109.8
2.7	0.96	112.8	2.2	1.45	148.1	2.7	0.66	107.8	3.0	0.57	93.1	2.9	115.4
3.7	0.84	98.7	3.7	0.84	85.8	3.7	0.59	96.4	3.9	0.66	107.8	3.7	97.2
4.5	0.88	103.4	4.5	0.87	88.9	4.7	0.62	101.3	4.9	0.55	89.9	4.7	95.9
5.7	0.99	116.3	5.6	0.98	100.1	5.7	0.63	102.9	6.0	0.59	96.4	5.7	103.9
7.7	0.83	97.5	7.6	0.91	93.0	7.9	0.59	96.4	8.0	0.51	83.3	7.8	92.6
12.0	0.87	102.2	12.0	0.83	84.8	11.9	0.62	101.3	11.5	0.65	106.2	11.8	98.6
22.0	0.62	72.1	20.5	0.84	85.8	19.9	0.61	99.7	19.3	0.66	107.8	20.4	91.4
30.8	0.75	88.1	29.3	0.93	95.0	28.3	0.51	83.3	29.6	0.70	114.4	29.5	95.2
Aver.	0.85	100.0		0.98	100.0		0.61	100.0		0.61	100.0		100.0

D.O. = dissolved oxygen, p.p.m.; D. = depletion, p.p.m.; R.D. = relative depletion.

The first group of runs, shown in Table I, covers a range of oxygen concentrations from 1.8 to 30 p.p.m., and sewage was added to give depletions of less than 1 p.p.m. For each series Table I shows the average dissolved oxygen concentration, D.O. (average of initial and final oxygen concentrations), the depletions, D., and the "relative depletion," R.D. The "relative depletions" are obtained by equating the average depletion for the series to 100 and converting the individual depletions to proportional numbers. These relative depletions facilitate comparison of the different series, and permit averaging without giving undue weight to those series having higher depletions.

The average relative depletions (last column) show a trend toward lower values at the higher oxygen concentrations. The irregular deviations of individual points from the general trend are not significant, as the erratic errors are large enough to account for the observed deviations.* The difficulty of measuring the small depletions not only re-

* The magnitude of this erratic error may be evaluated in terms of the "probable error." Letting d represent the deviation of a single relative depletion from the average for that oxygen range, n the number of such deviations, and N the number of values entering into the average, the probable error, P.E., of each average is:

$$\text{P.E.} = \frac{0.6745\sqrt{\frac{d^2}{n}}}{\sqrt{N}}.$$

From the data of Table I, the P.E. of each average relative depletion is calculated to be 3.6. Individual averages may be in error by as much as 2 or 3 times the P.E. If systematic errors are involved, they are superimposed on the pattern of erratic variations.

sults in these obvious deviations, but also allows the possibility of systematic errors. For example, slight variations of the temperature of the water bath might cause the bottles to expel small amounts of the sample and suck in water from the bath. The high-oxygen samples would lose oxygen, while the low-oxygen samples would gain oxygen. This error, however, would be opposite in direction to the effect which is indicated by Table I.

TABLE II.—*Influence of Oxygen Concentration on 5-day B.O.D.*

Series I (Filtered Raw Sewage)			Series II (Filtered Raw Sewage)			Series III (Filtered Effluent)			Series IV (Filtered Effluent)			Average	
D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	R.D.
8.45 to 3.35	5.10	105.8	8.21 to 2.40	5.81	108.2	8.17 to 0.75	7.42	111.1	8.31 to 0.76	7.55	119.8	5.0	111.2
10.0	5.26	109.1	9.7	5.70	106.2	9.4	7.33	109.7	8.1	7.30	115.9	9.3	110.2
18.2	5.01	103.9	18.9	5.57	103.7	18.5	7.12	106.6	19.2	6.29	99.8	18.7	103.5
28.2	4.52	93.7	27.9	4.98	92.7	22.5	7.06	105.7	26.6	5.99	95.1	26.3	96.8
36.0	4.23	87.7	33.5	4.78	89.0	37.4	4.47	66.9	37.8	4.37	69.4	36.2	78.3
Aver.	4.82	100.0		5.37	100.0		6.68	100.0		6.30	100.0		100.0

A second group of runs is represented in Table II. This group shows the influence of the higher oxygen concentrations determined by depletions large enough to be measured with greater relative accuracy. In the first line of figures the initial and final oxygen concentrations are shown for the lowest oxygen range to bring out the fact that in some cases the oxygen was depleted to less than 1 p.p.m. without showing any reduction of the demand.

A decrease of the rate of oxygen consumption with increasing oxygen concentration in these four runs is established beyond question. In each series each increase of oxygen concentration causes a decrease of B.O.D., with only one exception (at the first of Series I). Apparently the magnitude of the effect is variable, being greater with the effluent than with the raw sewage.

The data of Table II are shown graphically in Fig. 1, with separate lines drawn to represent the data of the raw sewage and of the effluent.

The fact that this group shows an effect considerably greater in magnitude than could be deduced from Table I probably may be explained by the systematic errors affecting the small depletions, as discussed before.

Table III covers further data obtained with small depletions at oxygen concentrations below 8 p.p.m. By using filtered samples and taking all possible care to minimize errors, the erratic deviations were materially reduced in comparison with Table I.

In one case (Series I) the oxygen was depleted to 0.10 p.p.m. with no reduction of the B.O.D., although in another case (Series IV) the B.O.D. value was somewhat low when the oxygen was reduced to 0.15 p.p.m. No significant difference appears between the results obtained with filtered raw sewage and filtered effluent.

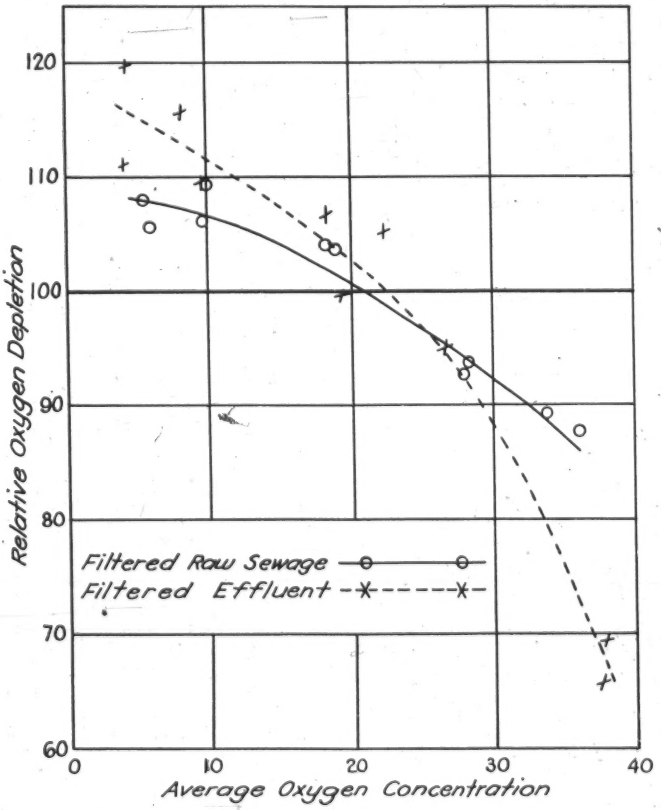


FIG. 1.—Influence of oxygen concentration on 5-day B.O.D. (data of Table II).

The data of this table are shown graphically in Fig. 2. The line apparently becomes steeper at the lower oxygen concentrations. This effect would appear considerably more pronounced if the doubtful value at the first of Series IV were eliminated.

A final pair of runs was made to determine the influence of oxygen concentration on the 2-day B.O.D., using filtered raw sewage. Results

TABLE III.—*Influence of Oxygen Concentration on 5-day B.O.D.*

Series I (Filtered Raw Sewage)			Series II (Filtered Raw Sewage)			Series III (Filtered Raw Sewage)			Series IV (Filtered Effluent)			Average	
D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	R.D.
1.48 to 0.10	1.38	104.7	1.40 to 0.67	0.73	107.6	0.95 to 0.29	0.66	110.8	0.92 to 0.15	0.77	94.2	0.75	104.3
1.7	1.32	100.2	2.0	0.73	107.6	1.9	0.58	97.4	1.4	0.85	104.0	1.7	102.3
2.5	1.32	100.2	2.8	0.65	95.8	3.0	0.63	105.7	2.6	0.83	101.6	2.7	100.8
3.4	1.27	96.5	3.6	0.67	98.7	3.8	0.60	100.7	3.8	0.85	104.0	3.7	100.0
4.5	1.30	98.7	4.9	0.64	94.3	5.0	0.61	102.4	5.1	0.81	99.1	4.9	98.6
5.3	1.30	98.7	5.9	0.68	100.0	6.1	0.55	92.3	6.0	0.81	99.1	5.8	97.5
7.7	1.33	101.0	8.0	0.65	95.8	8.4	0.54	90.7	7.5	0.80	97.9	7.9	96.4
Aver.	1.32	100.0		0.68	100.0		0.60	100.0		0.82	100.0		100.0

are shown in Table IV. The depletions are somewhat irregular in Series I, and hence in the average, but a decrease of the depletion with increasing oxygen concentration is clearly established. The magnitude of the effect is not significantly different from that observed with the 5-day B.O.D. The effect in these runs seems to be most pronounced between 30 and 40 p.p.m. as was the case in the runs represented by Table II.

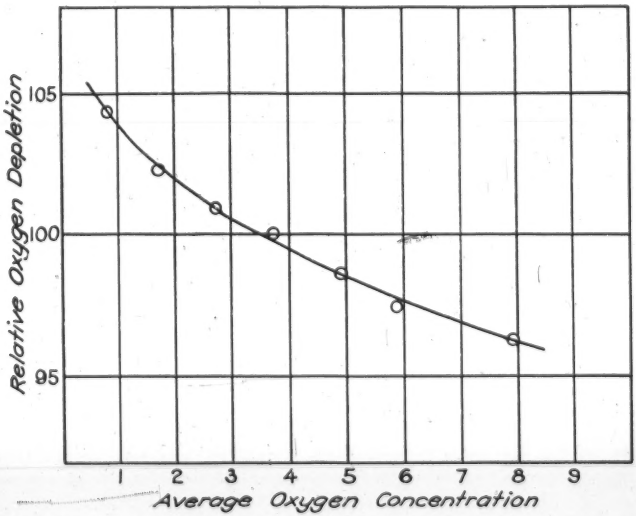


FIG. 2.—Influence of oxygen concentration on 5-day B.O.D. (average of four samples).

TABLE IV.—*Influence of Oxygen Concentration on 2-day B.O.D.*

Series I (Filtered Raw Sewage)			Series II (Filtered Raw Sewage)			Average	
D.O.	D.	R.D.	D.O.	D.	R.D.	D.O.	R.D.
4.8	6.84	115.3	5.7	5.15	105.4	5.3	110.3
10.2	7.04	118.6	10.7	5.07	103.8	10.5	111.2
19.1	5.51	92.9	19.3	5.00	102.3	19.1	97.6
29.5	6.17	104.0	28.5	4.81	98.4	29.0	101.2
39.6	4.11	69.3	39.0	4.40	90.1	39.3	79.7
Aver.	5.93	100.0		4.89	100.0		100.0

DISCUSSION

Very little data has appeared in the literature touching upon the possible influence of oxygen concentration on the biochemical oxygen demand. A study of the relative merits of air and oxygen for the direct determination of the biochemical oxygen demand was made by Sierp (1). He shows graphically the results of a comparison of the use of air and oxygen for determining the B.O.D. of activated sludge and of sewage, and includes also a comparison of the B.O.D. of diluted sewage by the ordinary dilution method and by the direct method using oxygen. In the case of sewage he agitated the sample every 3 or 4 hours; the activated sludge sample was probably shaken every hour. In either case, the oxygen concentration when pure oxygen was used was undoubtedly much higher than when air was used, but must have been substantially below the saturation value much of the time, especially early in the run when the rate of oxygen consumption is high.

The graphs of Sierp show no appreciable difference between air and oxygen in the early stages of the runs (no difference for two days in the cases of sewage and diluted sewage; for seven days in the case of activated sludge), but thereafter in each case the oxygen consumption was substantially lower where oxygen was used. For example, in the case of the sewage sample the oxygen consumption from the 2nd to the 10th day was 83 per cent as great with oxygen as with air. From the beginning of the run to the 10th day the oxygen consumption was 90 per cent as great with oxygen as with air. At the end of 20 days the curves come together again; this may be accounted for by a difference in the onset of nitrification. Sierp evidently did not consider that the differences which his experiments showed were sufficient to be important, and he recommends the use of oxygen. It appears, however, that his results at least partially substantiate the findings of this research.

Heukelekian (2) made a study of the effect of oxygen concentration on bacterial numbers, and determined incidentally the oxygen consumption. He reached the surprising conclusion that bacterial growth is retarded at oxygen concentrations between 4 and 6 p.p.m. in comparison

with higher and lower D.O. concentrations. Careful examination of his data shows that the conclusion is not warranted by the data. Referring to Heukelekian's Table II and Fig. 1, it is seen that averages were taken of bacterial counts which differ among themselves by very large amounts. The probable error due to the random combinations of the erratic variations is 130 (thousands per c.c.) where five values were averaged and 145 where four values were averaged. Smooth curves can easily be drawn through the data of his Fig. 1 without missing the points by more than would be expected from theory. That is, half of the points should not deviate from the curves chosen by more than the P.E. (probable error), and one point out of each group of seven may be expected to deviate by 2.9 P.E. The fact that all three curves of Fig. 1 show minima at a D.O. concentration of 5 cannot give much added support to Heukelekian's conclusion in view of the fact that this phenomenon is due almost entirely to abnormally high counts in Series 2 in the 3.5–2.1 range, indicating some systematic source of variation uniquely affecting that Series. The apparent decrease of bacterial growth indicated by his data at the high oxygen concentrations may be real, or may again be due to systematic errors.

With regard to the consumption of oxygen, Heukelekian presents data and calls attention to an apparent retardation of oxidation in the D.O. range around 5 p.p.m. However, he states that "the depletions were so small that it would be difficult to draw conclusions from the observed differences in the depletions." Careful analysis of the data shows that all of the apparent effects can be accounted for on the basis of random and systematic errors.

The influence of oxygen concentration on the biochemical oxygen demand as indicated from this present study may have some significance in two directions. With regard to the determination of sewage strength by B.O.D. measurements, it would appear that the use of pure oxygen in the direct method, as recommended by Sierp, would not be good practice, especially in view of the large magnitude of the effect when the D.O. is over 30 p.p.m. Fortunately the effect is not large below 8 p.p.m. and in the ordinary dilution method no serious error due to variations of the D.O. concentration is introduced.

In the activated sludge process, it would be desirable to know the optimum oxygen concentration for efficient purification. The conditions in the aeration tanks are so different from the conditions in B.O.D. bottles that it is not permissible to assume that the influence of oxygen concentration would be the same in both cases. However, in the absence of other information, it may be supposed that the rate of oxidation of the sewage impurities at least is not increased by increasing the oxygen concentration, and that for economical operation an activated sludge plant may be run with the lowest oxygen concentration which can be consistently maintained.

Summary

The B.O.D. values of diluted sewage and partially oxidized effluent were found to decrease as the dissolved oxygen concentration increased, the effect being consistent over the entire range from 0.8 p.p.m. to about 40 p.p.m. Different samples vary in the magnitude of the effect. The decrease in the rate of oxygen consumption when the oxygen concentration was increased from 6 to 36 p.p.m. amounted to 20 per cent in the case of two filtered sewage samples, and to 37 per cent in the case of two filtered samples of a partially oxidized effluent.

References

1. F. Sierp, "Fortschritte in der Kenntnis des biochemischen Sauerstoffbedarfs," *Technisches Gemeindeblatt*, Sept. 12 to Dec. 20, 1931.
2. H. Heukelekian, *This Journal*, **8**, 415 (1936).

COMMENTS ON DR. POMEROY'S PAPER*

By Willem Rudolfs and H. Heukelekian

Chief and Associate, Division Water and Sewage Research, New Brunswick, N. J.

From a theoretical standpoint, the effect of oxygen concentration on the biochemical oxygen demand is of considerable interest, regardless what the oxygen concentration of the dilution water may be, because the method of B.O.D. determination is assumed to indicate what the behavior of sewage or effluents will be in streams varying constantly in dissolved oxygen. If variations in the oxygen tension play an important role the dilution method loses considerable of its importance and the so-called "direct oxygen" methods have very little value. From a practical point of view, the effect of oxygen concentration is highly important in connection with oxidation devices and the load to be handled by clean and polluted streams. The oxygen tension may vary from day to day or from hour to hour, resulting in useless or insufficient supply of air or allowing the oxygen tension to become so low (trickling filters) that a part of the efficiency is destroyed. In calculating the load to be handled by streams, factors would need to be introduced to take care of the numerous and constant variations of the oxygen tension in the water.

The problem of the oxygen consumption rate at different oxygen tension values dissociates itself into two phases and should be discussed accordingly. The first phase of the problem deals with the effect of oxygen concentrations up to the atmospheric saturation value and the second phase deals with the effect of concentrations up to the saturation value of pure oxygen.

Before a critical analysis of the evidence is presented the author should be commended for the painstaking and careful work. The pre-

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Division Water and Sewage Research.

cision of his analytical method as indicated by the detail results, which are not part of the present paper, is praiseworthy. The individual figures given in the tables are based on very closely checking quadruplicates and in some cases eight analyses. The average results of four series in each table therefore represent sixteen analyses for a given D.O. concentration. This point should be emphasized because in normal B.O.D. work the number of individual tests averaged does not exceed three.

Normal Concentrations

In spite of this careful and precise work the *individual* series in the normal D.O. concentration range does not show a consistent tendency. The tendency of the *average* of four series in the different tables in the range of D.O. covering from 1 to 8 p.p.m. is somewhat more consistent. In other words, consistent averages are obtained from inconsistent individual series and naturally the question arises as to how these averages might be affected by leaving out one or the other of the individual series. It is also interesting to know what the magnitude of the changes would be in p.p.m. B.O.D. as well as their variations.

The results covering the lower range of dissolved oxygen concentration are most complete and consistent (Table III). With the aid of additional data furnished us by the author the depletions given in Table III have been calculated in terms of B.O.D. The calculations are shown in Table A, together with the decrease or increase in B.O.D.

Table A.—*B.O.D. Equivalents of the D.O. Depletions and their Averages (p.p.m.)*

	Series I	Series II	Series III	Series IV	Average 4 Series
	86.0	51.7	47.0	19.2	51.3
	83.0	51.7	41.5	21.2	49.3
	83.0	46.0	45.0	20.7	48.7
	79.0	47.5	43.0	21.2	47.7
	81.0	45.5	43.5	20.2	47.5
	81.0	48.0	39.4	20.2	47.1
	83.0	46.0	38.6	20.0	46.9
Decrease	3.0	5.7	8.4	+0.8	4.4
Decrease %	4.5	10.0	17.0	+4.2	8.5
Maximum variation	7.0	6.2	8.4	2.0	4.4

+ means increase.

from the lowest oxygen concentration to the highest, and the maximum variations. A perusal of the table will show that (1) the tendency of decrease is not uniform within each series, (2) in three out of four series the maximum variation within the series is greater than the decrease, (3) the greatest variations are not with the highest B.O.D. equivalents, either in p.p.m. or percentages, (4) the variations among the series (from an increase of 4.2 per cent to a decrease of 17 per cent) are considerably greater than the average percentage decrease for all

series. In view of the extreme precision of the technique the average decrease might be significant, if the results were consistent, but its lack reduces the value of the results greatly.

By averaging the four series a fairly consistent tendency is noted with a maximum variation in B.O.D. of 4.4 p.p.m. or 8.5 per cent. However, by averaging different combinations of three out of the four series the regularity of decreasing B.O.D. values with increasing dissolved oxygen concentration disappears with certain combinations to a greater extent than with others. The groups of B.O.D. averages calculated are shown in Table B. Even with these averaged combinations two out

TABLE B.—*Data from Table III. Groups of Averages of B.O.D. Equivalents of the D.O. Depletions (p.p.m.)*

Series I, II, III	Series I, II, IV	Series II, III, IV	Series I, III, IV
61.8	52.3	39.3	50.7
58.7	51.9	38.1	48.6
58.0	49.9	37.2	49.6
56.5	49.2	37.2	47.7
56.6	48.9	36.4	48.2
56.1	49.7	35.8	46.8
55.8	49.6	34.8	47.2
Decrease 6.0	2.7	4.5	3.5
Maximum variation 6.0	3.4	4.5	3.9

of the four combined series show a greater maximum variation than the decreases. The magnitude of the decrease and the regularity of the decreases are perhaps better visualized by plotting the p.p.m. B.O.D. against the different oxygen concentrations of the average of the four series and by comparing the curves with the more irregular decreases of averages of three series (Fig. A).

The author has pointed out that experiments with small depletions (less than 1.0 p.p.m.) are subject to criticism due to systematic errors. The experiments with large depletions are likewise questionable due to the appreciable decrease in the initial dissolved oxygen concentration during incubatoin. In other words, in studying the effect of a given dissolved oxygen concentration on the rate of consumption of oxygen the initial concentrations decreased continuously and appreciably. (In the lower dissolved oxygen concentrations the decrease amounted to 50 or more per cent of the original dissolved oxygen.) From a practical viewpoint it is doubtful whether the effect of the normal dissolved oxygen concentrations on the rate of oxygen consumption can be registered on the B.O.D. determination as commonly run by the dilution method even if as many as three different dilutions are used.

There are, further, certain observations which indicate that oxygen consumption is not affected within the normal range of dissolved oxygen concentration. The first observation comes from the B.O.D. determination itself by the dilution method where two or more dilutions of a given sample are made. The results do not indicate any tendency

for a lower oxygen utilization or a lower B.O.D. value with the higher dilutions which results in a final relatively high dissolved oxygen concentration. In this determination the important factors seem to be a sufficient dilution to give an appreciable depletion (1 p.p.m. or more)

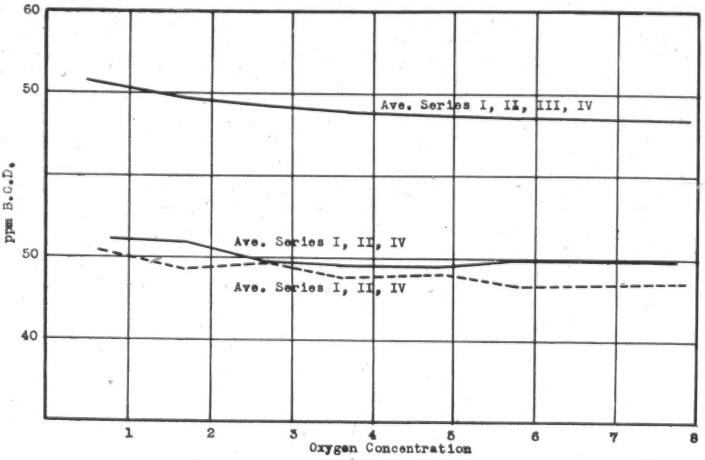


FIG. A.—Magnitude and decreases of calculated B.O.D. values (based on Pomeroy's Table III).

and yet not too high a concentration of the polluting material in the final mixture so that the final dissolved oxygen is not depresssed below 1.0 p.p.m. These limitations are set by the systematic errors caused by too small or too great a depletion. Within this range and limitation (with final dissolved oxygen concentration above 1 p.p.m. and a depletion of more than 1 p.p.m.) the B.O.D. values obtained with two or more dilutions are uniform within the experimental error.

The second indirect evidence on this question can be adduced from the observations regarding the efficiency of purification of sewage by the activated sludge process. Although there have been no accurately controlled experiments with the dissolved oxygen concentration as the only variable factor there are a number of observations which seem to indicate that above a minimum dissolved oxygen concentration (variously set from 0.5 to 1.0 p.p.m.) the efficiency of the process is not affected by the dissolved oxygen concentration.

In the third place, results with aerobic decomposition of sewage sludge deposits seem to indicate essentially the same rate and total demand for all concentrations between 0.1 and 6.0 p.p.m. dissolved oxygen (1).

The author levels criticism at Heukelekian's results pertaining to the retardation of growth at oxygen concentrations between 4 and 6 p.p.m. The criticism is based on the presentation of averages of bac-

terial counts which differ among themselves by very large amounts. It is contended that the depression noted in the average curve (Fig. 1 of H's paper) is fortuitous and smooth curves can easily be drawn. It is stated that the abnormally high counts in series II in the 3.5 to

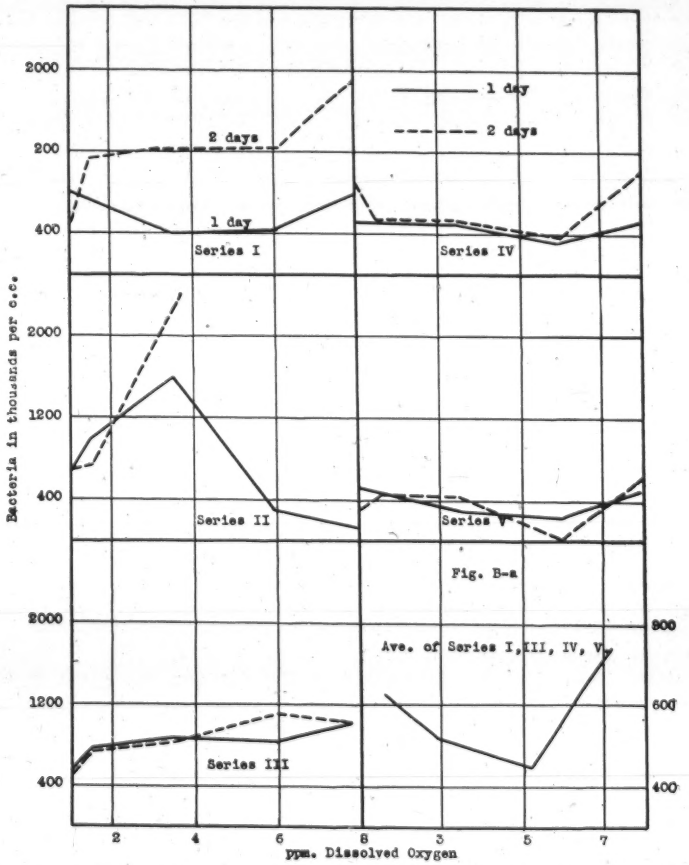


FIG. B.—Bacterial numbers of individual series together with average of four series (from Heukelekian's Fig. 1).

2.1 dissolved oxygen range vitiate the results. We have therefore replotted (Fig. B) the individual series separately without averaging. It will be seen that the bacterial counts after one day show some depression within 3.5 to 6.0 p.p.m. dissolved oxygen concentration in

four cases out of five, the only exception being Series III, where practically no change is recorded. On the other hand by leaving out Series II which has been criticized as affecting unduly the average count, the results obtained for the one-day count are as in Fig. B–A. The depression of bacterial numbers in the middle range of dissolved oxygen concentration (initial average dissolved oxygen 3.0–5.0) is again evident. It should be noted that the results presented in Heukelekian's Table III, with closer intervals of D.O. concentration, and which were not included in the averages of Heukelekian's Table II, indicate a similar depression of bacterial numbers at a range of 4.5 to 5.5. Attention is also called to the work by Waksman and Carey (2), who have noted similar depressions of bacterial numbers at a dissolved oxygen concentration of 5.6 p.p.m.

Higher Concentrations

The effect of dissolved oxygen concentrations above the atmospheric saturation value appears to be more definite. However, if the averages are calculated for the filtered sewages and effluents (Tables I and II) at different oxygen concentrations significant changes occur only after the dissolved oxygen concentration is above 30 p.p.m. This is illustrated by the following results:

Sewages		Effluents	
P.p.m. D.O.	R.D.	P.p.m. D.O.	R.D.
11.5	106	11.9–12.0	96.1
18.2–19.3	105	18.5–22.0	91.7
27.9–29.6	100.3	28.3–30.8	88.7
33.5–36.0	88.5	37.4–37.8	68.2

In the range between 10 to 30 p.p.m. the tendency is similar to the range of 1 to 10 p.p.m., except that the individual variations are greater. The practical significance of these results would seem to be that supersaturation of dilution water, and the use of pure oxygen, as suggested by some German and English investigators, produce questionable results.

The author states that bacterial decreases noted at high dissolved oxygen concentration (15 p.p.m. and above) may be real or may again be due to systematic errors. It would be logical to consider the lower oxygen consumption rates at such high concentrations of dissolved oxygen observed by the author as a confirmation of the results obtained from the bacteriological phase of the study reported earlier by Heukelekian.

Heukelekian stated definitely at the time "We have no results on the rate of consumption of oxygen at the different dissolved oxygen tensions. The amount of sewage added and consequent depletions were so small that it would be difficult to draw conclusions from the

observed differences in the depletions'' (3). The difficulties encountered by Pomeroy were clearly envisioned at that time. No attempt was therefore made to compare the depletions and rate of consumption. The dissolved oxygen figures were given only for the sake of showing the initial and final concentration of dissolved oxygen in the different series.

The author states in reference to Fig. 1 of Heukelekian's article that ''smooth curves can easily be drawn through the data of his Fig. 1 without missing the points by more than would be expected from theory.'' We are not aware of any theory regarding the effect of dissolved oxygen concentration on bacterial numbers. The experiment was designed to find out the facts. It is not against any formulated known theory that total bacterial population may be adversely affected by a certain dissolved oxygen concentration. In fact it is quite probable that certain groups of organisms may be more adversely affected at some dissolved oxygen concentration than others, thereby causing a depression in the total bacterial population. According to Marshall (4) oxygen may be considered a poison as it will kill bacteria at very low concentrations. Some bacteria are extremely sensitive to oxygen and die if exposed to ordinary atmospheric oxygen. Obligate anaerobes are examples of this type.

REFERENCES

1. Baity, *Water Wks. and Sew.*, **84**, 354 (1937).
2. Waksman and Carey, *Jr. Bact.*, **29**, 531 (1935).
3. *This Journal*, **8**, 420 (1936).
4. Marshall, ''Microbiology,'' pp. 15–157, 2nd Ed.

AUTHOR'S CLOSURE

By Richard Pomeroy

It is scarcely to be expected that the rate of biochemical oxygen demand will be absolutely unaffected by variations in such an important factor as the oxygen concentration, even in the range below atmospheric saturation. If the oxygen concentration influences the rate of bacterial growth, as Rudolfs and Heukelekian contend, and as undoubtedly is the case, then it is all the more certain that oxygen consumption is also influenced. The data which I have presented were secured in an attempt to determine the magnitude and direction of the effect.

The results of the experiments show some irregularities, but not more than is generally expected in oxygen demand work. In the case of Table III, smooth curves can be drawn through the data of each series, and in no case will the points be missed by an average of more than 0.02 p.p.m. of demand, except for the doubtful point at the first of series 4.

The data of Table III apparently show a downward trend of oxygen demand with increasing oxygen concentration. Various criteria may

be used to determine whether the apparent trend is significant. Among such criteria which are acceptable according to standard methods of statistics is the "rank-difference coefficient of correlation," explained in various textbooks and handbooks (1). The coefficients of correlation of the four runs of Table III, indicating in each case a downward trend, are, respectively, 0.322, 0.607, 0.750, and 0.071. A series of seven points may of course show an apparent trend due to accidental distribution of values. The probabilities of accidental correlation coefficients of the magnitudes shown are respectively 24.89 per cent, 8.33 per cent, 3.31 per cent, and 45.32 per cent. A proper combination of these values indicates that there is one chance in 183 that the apparent trend in Table III is accidental.

If the six oxygen ranges below atmospheric saturation in Table I be considered, the trend is equally obvious. There is one chance in 193 that this trend is accidental. The two groups of data, both pointing so positively to a trend in the same direction, are substantial proof that a trend did exist under the conditions which prevailed. This conclusion is not shaken by the line of reasoning followed by Rudolfs and Heukelekian in their discussion. The nature of the experiment was such as to make it probable that this trend was due to variations of oxygen concentration.

The scattering of the points of course introduces uncertainty as to the exact course of the trend curve. The remarkable smoothness of the curve (Fig. 2) representing the average results of Table III, is fortuitous. The probable error of each point on the curve is 1.3. This means that the curve probably varies from the "true curve" (*i.e.* the curve which would be obtained from a large number of similar experiments with the same materials) by as much as 1.3 per cent for a part of its length. Thus the curvature might be different from that indicated; the data might be represented by a straight line, or there might be a minimum in the curve. However, there is only one chance in 25 that any particular point differs by more than 4 per cent from the "true curve."

A further restriction to generalization of the data must be borne in mind, *i.e.* the fact that these experiments were limited to the sewage and effluent of one plant. Other types of pollutional materials, other media, and other microflora and fauna might give different results.

It is to be expected that bacterial growth, as well as oxygen consumption, will be affected by oxygen concentration. The point at issue on the bacterial data is whether the irregularity noted by Heukelekian, that is, a maximum around 3 p.p.m. of D.O., followed by a minimum at 5 p.p.m. and then another maximum, is proved by his data to be a real effect. The question is best judged by the magnitude of the apparent average effect in comparison with the probable error due to random combinations of erratic variations. As was pointed out previously, the probable error of each average of five results is 130 thousands. In comparison with this, the apparent decrease in activity around 5 p.p.m. is not significant.

Rudolfs and Heukelekian attempt to justify their conclusion on the basis of the number of instances in which there is a decrease in the count upon going from the range around 3 p.p.m. to the range around 5 p.p.m. of D.O. The 1-day counts show this effect in 4 out of 5 instances. This does not constitute proof in the scientific sense. To illustrate this point, if a coin be tossed five times, there are 3 chances in 16 that a specified side will come up 4 or more times. Thus the apparent effect may easily be a matter of chance. At the end of 2 days the decrease appears in 3 out of 4 cases, and at the end of 3 days in only 1 out of 4 cases (omitting one case which showed no change). The decrease appears, altogether, in 8 out of 13 cases. If a coin be tossed 13 times, there is a 29 per cent chance that a specified side will come up 8 or more times. The predominance of instances showing the effect is by no means great enough to prove anything.

In the case of Heukelekian's Table III, the count at the beginning of the run in the second oxygen range is so large that the initial condition may have influenced the results.

The data of Waksman and Carey, which have been cited in the argument, are reproduced in the following table, with the oxygen concentrations changed to mg. per liter (approx. p.p.m.).

Start		2 days		5 days	
D.O. mg./l.	Bact. per c.c.	D.O. mg./l.	Bact. per c.c.	D.O. mg./l.	Bact. per c.c.
6.79	107	6.58	912,000	4.30	1,426,000
6.32	88	6.24	9,350	5.06	1,098,000
6.20	78	6.06	8,000	5.91	812,000
5.64	69	5.54	2,950	5.48	5,150

These tests were made with sea water. The conditions of the experiments were such as to admit of the possibility that the results were influenced by factors other than the oxygen concentration. This was recognized by the authors, who stated: "This modification of bacterial activities by reducing the oxygen tension of the water is of such distinct interest that, before the subject has been studied in further detail and before the modifications in the physical and chemical conditions of the water, such as changes in hydrogen-ion concentration, are better understood, no broad generalizations can be made." But even if the variations in bacterial growth are considered to be due solely to the influence of oxygen concentration, the results still do not substantiate Heukelekian's finding of a maximum in activity around 3 p.p.m. followed by a minimum; they show a consistent increase in growth with increase of initial D.O. over the range studied.

It is interesting to note that these data show a large variation in oxygen consumption with changes of initial D.O., but the effect is opposite in direction to that observed in my experiments.

The "theory" on the basis of which I claimed that smooth curves could be drawn through the data of Heukelekian, and which was the subject of discussion in the last paragraph of the comments by Rudolfs and Heukelekian, was the purely mathematical theory of errors.

If a smooth curve be drawn through the data of Heukelekian, then such a curve will indicate a general tendency toward greater bacterial activity at higher oxygen concentrations throughout the range of moderate oxygen concentrations. If this fact be correlated with the results of the experiments on the rate of oxygen consumption, it will lead to the conclusion that higher oxygen concentrations tend to favor organisms with lower specific rates of oxygen consumption. However, there is no assurance that the different samples of sewage used in the two studies would show the same behavior, and hence the conclusion is of doubtful value.

The discussions which Rudolfs and Heukelekian and I have made of each others papers in each case point toward the desirability of further data on the important questions which have been the subject of our researches. Some effect such as that which Heukelekian claims may be real, although it does not appear to me to be probable. Doubtless further data will become available in the future to throw more light on this point. Also, it is to be expected that other laboratories in the future will repeat experiments of the type of mine, with completeness and accuracy exceeding that upon which Rudolfs and Heukelekian have so generously complimented me, and it will be interesting to find from such experiments what generalizations can be drawn.

REFERENCE

1. "Handbook of Chemistry and Physics," Chemical Rubber Publishing Co., 21st Edition, page 287.

Plant Operation

SEWER RENTAL LAWS IN MICHIGAN*

By George H. Sandenburgh

City Engineer, Ann Arbor

Although this paper deals primarily with a review of sewer-rental practice in Michigan, it is thought it might be of some interest to give a brief review of the status of sewer rental laws throughout the United States. Table I is taken from the 1936 issue of the Municipal Index.

Table I

	Enabling Act	Date Passed	Do Cities Charge Sewer Rentals	
			With State Act	Without State Act
Ala.	Yes	1933	Yes	—
Ariz.	No	—	—	Yes
Ark.	Yes	1933	Yes	—
Calif.	Yes	1933	No	—
Colo.	No	—	—	Yes
Conn.	Yes	1931	No	Yes *
Del.	No	—	—	†
Fla.	Yes	1935	Yes	—
Ga.	No	—	—	Yes
Idaho	No	—	—	No
Ill.	Yes	1933, 1934	Yes	—
Ind.	Yes	1932, 1935	Yes	—
Iowa	Yes	1931, 1933	Yes	—
Kans.	Yes	1923, 1933	‡	—
Ky.	Yes	1926	Yes	—
La.	Yes	1934	Yes	—
Maine	Yes	1933	No	—
Md.	Yes	1927	Yes	—
Mass.	Yes	§	Yes	—
Mich.	Yes	1927, 1929	Yes	—
Minn.	Yes	1935	Yes	—
Miss.	Yes	1935	Yes	—
Mo.	No	—	—	No
Mont.	Yes	—	No	—
Nebr.	No	—	No	—
N. H.	Yes	1933	Yes	—

* Manchester purchased a private system and collects rentals.
† Georgetown had Special Act passed in 1931.
‡ Ellsworth only 3d class city using rentals. Wichita has Special Law.
§ Authority given by General Laws, annual assessments declared constitutional in 1901.

* Presented at the Thirtieth Annual Conference of the Michigan Sewage Works Association, East Lansing, March 30–April 1, 1938.

TABLE I—*Continued*

	Enabling Act	Date Passed	Do Cities Charge Sewer Rentals	
			With State Act	Without State Act
Nev.	Yes	1919	—	—
N. J.	Yes	1917	Yes	—
N. Mex.	No	—	—	Yes
N. Y.	Yes	1929	No	—
N. C.	Yes	1933	Yes	—
N. Dak.	Yes	1933	Yes	—
Ohio	Yes	1933	Yes	—
Okla.	No	—	—	Yes
Ore.	Yes	1933	Yes	—
Pa.	Yes	1935	Yes	—
R. I.	No	—	—	No
S. C.	No	—	—	No
S. Dak.	No	—	—	—
Tenn.	Yes	1933, 1935	Yes	Yes ||
Texas	No	—	—	Yes
Utah	No	—	—	—
Vt.	No	—	—	—
Va.	No	—	—	Yes ¶
Wash.	Yes	1909	Yes	—
W. Va.	Yes	1933	Yes	—
Wis.	Yes	1929, 1933	Yes	—
Wyo.	Yes	1935	—	—
Dist. of Col.	No	—	—	No

|| Dayton charged rentals for several years before Act was passed.
¶ Through charter provisions.

Examination of this table shows that thirty-two states now have enabling acts, and that twenty-five states are taking advantage of these acts and are charging sewer rentals for the construction of sewage treatment plants or for the operation and maintenance of sewage treatment plants and sewerage systems or for both. Of the seventeen states, including the District of Columbia, which have no enabling act, there are seven states in which cities are charging sewer rentals either through charter provisions or through their interpretation of the general law of the state.

A detailed review of the status of sewer rental laws in the forty-eight states would be very voluminous and too long a paper for this conference. Such a review has been published in the 1936 issue of Municipal Index.

A study of Table I shows that only three enabling acts were passed previous to 1920, six from 1920 to 1930, and twenty-one since 1930. This shows that there were very few sewer rental laws in operation prior to 1930, and indicates that the practice is new and one that has come into general use during the past seven years.

The advent of sewer rental laws may be traced to the activity of State Departments of Health in their campaigns to put a stop to the pollution of the rivers and lakes throughout the nation. Municipalities, faced with the necessity of building a sewage treatment plant, found that they could not finance the cost of construction, operation and maintenance of such a plant from the usual sources of revenue, namely the property tax, and of necessity, looked for other sources of revenue, and the sewer rental laws are the result. Sewer rental laws are fair because the property served pays for the service received.

It is a generally accepted fact that moneys received from sewer-rental charges may be justly used for the construction, maintenance and operation of sewage treatment plants and main- and intercepting-sewer construction and maintenance. These moneys should not be used for the construction of storm sewers or for the extension of the lateral system of sanitary sewers. In some instances sewer-rental ordinances have been defeated because they were designed to cover the cost of construction of storm and lateral sewers. The best practice is to limit the use of sewer-rental revenues to the construction of sewage treatment plants, their maintenance and operation, and possibly the construction of trunk sewers from the city to the treatment plant and the maintenance of the sanitary sewer system. The cost of construction of lateral sewers should be raised by special assessment against the property benefited, and the cost of storm sewers either by special assessment or from general tax revenues.

Michigan's first so-called sewer rental law was passed in 1927 and amended in 1929. This law was Section 3 of Act 320, Public Acts of 1927, and Act 160, Public Acts of 1929. Section 3 reads as follows:

> The legislative body of any such governmental agency or municipality or the respective legislative bodies of such governmental agencies and municipalities, who may have agreed to jointly own and operate intercepting sewers or sewage-treatment plants, may create a separate board or may designate certain officials of the governmental agencies or municipalities, to have the supervision and control of such intercepting sewers or sewage and garbage disposal plants. The legislative body, respective legislative bodies, or such board, may make all necessary rules and regulations governing the use, operation, and control thereof. The legislative body or respective legislative bodies may establish just and equitable rates or charges to be paid to them for the use of such disposal plant and system by each person, firm or corporation whose premises are served thereby. If the service charge so established is not paid when due, such sum may be recovered by the governmental agencies or municipalities in an action of assumpsit, or it may be certified to the tax assessor and assessed against the premises served, and collected or returned in the same manner as other county or municipal taxes are certified, assessed, collected and returned.

I have never heard of a plant being built under the provisions of this law. While it appears to be easy to take advantage of the provisions of this Act, there are several things that must be done that are not easily done. Mortgage bonds may be issued by the legislative body of a municipality without a vote of the people, but the bonds must contain a franchise feature which requires such a vote. Bonds can be issued by a municipal, legislative body after a court of competent jurisdiction

has ordered a plant built. The present Revenue Bond Act is the better law to work under.

The Revenue Bond Act, or Act 94 of the Public Acts of 1933, was enacted in order that Michigan cities might avail themselves of the opportunities offered by the Public Works Administration. However, the Public Works Administration would not approve projects to be financed under the provisions of this Act until the Supreme Court of the State had passed on its constitutionality. Suit to test the constitutionality of the Act was filed by the cities of Ann Arbor, Traverse City and Charlevoix. In a decision handed down on May 4, 1934, the Supreme Court held the Act constitutional. The title of the Act reads as follows:

> An Act to authorize any county, city, incorporated village, township, school district, port district or metropolitan district, of the state of Michigan, to purchase, acquire or construct housing facilities, garbage, rubbish and/or sewage-disposal plants and systems, incinerators, public markets and storage facilities, merchandise marts, industrial marts, commercial marts, yacht basins, harbors, docks, wharves, terminal facilities, bridges over, tunnels under, ferries across rivers, streams and/or channels within or bounding such unit, community buildings, stadiums, convention halls and auditoriums, dormitories, hospitals, buildings devoted to public use, parks and recreational facilities, reforestation projects, aeronautic facilities and marine railways, either within or without the limits of such county, city, incorporated village, township, school district, port district or metropolitan district; to authorize any county, city, incorporated village, township, school district, port district or metropolitan district in the state of Michigan, now or hereafter owning and operating any such projects, to improve, enlarge, extend or repair the same; and for any such purpose or purposes to authorize any such county, city, incorporated village, township, school district, port district or metropolitan district to issue self-liquidating revenue bonds, payable solely from the revenues derived from the operation of such project; to regulate the issuance, sale, retirement and refunding of such bonds; to regulate the use of the revenue of such projects when any such bonds are issued or outstanding, and for other purposes.

There are about four different methods of applying sewer rental charges in use. They are as follows:

1. Single charge per connection.
2. Charge based on type of sewer connection.
3. Charge based on volume of water consumed.
4. Charge based on number of fixtures.

Of the 30 municipalities in Ohio which have sewer rental ordinances in operation, 13 base the charge on the volume of water used, as shown by the meter records of the Water Department. Seventeen Ohio municipalities use the flat rate basis of charge for sewer rental. This flat rate basis is divided into three general classes.

1. The single charge per connection with no distinction as to type of premises served.
2. The flat-rate charge per connection, varying according to the number and type of fixtures in the building served.
3. The flat-rate charge which varies according to the type of premises served.

The latest information obtainable from Indiana shows that there are 67 sewage treatment plants in the state, 19 of which operate on the sewer rental basis. The sewer service charge in 15 of these 19 cities is based on the metered water consumption.

In Illinois there are 23 municipalities operating sewage treatment plants under sewer rental ordinances. Of these 23 municipalities, 12 base their sewer service rates on the water consumption. Wisconsin has 3 municipal sewage treatment plants operating under sewer rental ordinances, 2 on a flat-rate basis and the other on a fixed charge plus fifty per cent of the water bill. Several existing plants are considering sewer rental ordinances, and a number of new plants, now under construction, will use this method of financing.

Of the 73 municipalities in Michigan operating sewage treatment plants, 13 have sewer rental ordinances. The following table summarizes the practice in these municipalities.

	Basis of Charge
Alma	Volume of water consumed
Ann Arbor	" " " "
Battle Creek	" " " "
Caro	Flat rate per connection
Charlevoix	No report
Grand Haven	Volume of water consumed
Jackson	" " " "
Ludington	" " " "
Monroe	" " " "
Muskegon	" " " "
Muskegon Heights	" " " "
St. Ignace	No report
Traverse City	Volume of water consumed

You will note that 10 of the 11 cities reporting, base their charge on the volume of water consumed. This basis of charge seems to be the most popular and is the most practicable where the water consumption is metered and municipally owned.

The original Ann Arbor ordinance was passed August 10, 1934, but was amended December 17, 1937, before the rates were put into effect. I quote Section 7 of the ordinance, which, with proposed amendments, pertains to rates.

Section 7. The bills for services furnished by said Sewage Disposal Plant shall be levied upon each lot or parcel of land, building, or premises (hereinafter called premises) having any sewer connected with the sanitary sewer system, on the basis of the quantity of water used thereon or therein as the same is measured by the City of Ann Arbor Water Meter there in use. If any premises has any sewer connection with the sanitary sewer system, but is not a user of water which is measured by a City of Ann Arbor Water Meter, the quarterly charge shall be fixed by resolution of the Common Council. The Common Council of the City of Ann Arbor may classify the users of sewer service according to the quantity of water used, and charge such rates to the users in each class as it may deem reasonable.

Where it is evident that certain users of water use more water in the summer months for non-sprinkling purposes than they do in the winter months, the Common Council may order such users billed on the basis of water used in each month or each three-month period.

In cases where premises have a private water supply, the Common Council may order a water meter installed to measure the amount of water used in order to establish a basis for the sewage service charge, and the quarterly charge shall be fixed by resolution of the Common Council.

The bills for sanitary sewer services shall be prepared by the Water Department and collected at the same time and in the same manner as provided for water bills. The Water Department is hereby authorized to enforce the payment of such sewer service bills by shutting off the user's water supply, or an action of *assumpsit* may be instituted by the City against such user. Moreover, such bills for sanitary sewer services shall constitute a lien on the premises served by such a connection, and if not paid within ninety days may be certified to the City Assessor who shall place the same on the tax roll of the City. Such charges, so assessed, shall be collected in the same manner as general city taxes.

The rates to be charged for the sanitary sewer services are hereby fixed and determined to be as follows for each three-month period:

1. For the first 1,500 cu. ft. of water used 8.75 cents per 100 cu. ft.
2. For the next 98,500 cu. ft. of water used 5.25 cents per 100 cu. ft.
3. Over 100,000 cu. ft. of water used 3.50 cents per 100 cu. ft.
4. Minimum rate 75 cents, no discount.

7–5. Ten per cent discount allowed on all bills, except minimum rate paid within ten days from date of bill. Said rates shall be applied to the water billed on January first, February first, March first, April first, May first, and June first, except as herein provided. Billing on July first and October first shall be for the same amount as billed on April first, regardless of the amount of water used. Similarly the billing on August first and November first shall be for the same amount as billed on May first and the billing on September first and December first shall be for the same amount as billed on June first. Consumers billed for the first time in any month shall be charged at the established rates.

If any premises are billed for water on a monthly basis, they shall also be billed for sanitary sewer service on the same basis. The sanitary sewer service billing on the first of May, June, July, August, September, and October will be the same as billed on April first, unless application is made as provided in the next paragraph.

Nothing herein contained shall prevent the owner or occupant of any premises from electing to pay for sanitary sewer service on the basis of water used in every three-month period, provided such owner or occupant makes application in writing to pay on this basis for at least one year from the date of the next billing, following the date of application.

Nothing herein contained shall prevent any owner or occupant of a premises from making a division in the water service pipes, supplied with water through a single meter, so that, through the installation of one extra meter, the water used for purposes from which the waste water does not enter the sanitary sewer system can be measured separately from that water used for other purposes. No sanitary sewer service charge shall be made for such properly measured water used for purposes for which the waste water does not enter the sanitary sewer system.

When such a division of service is desired, application shall be made by the water consumer to the Board of Public Works, and when such division of service is certified to by the Plumbing Inspector and approved by the Board of Public Works, a meter, as above provided, shall be installed by the Water Department.

If by any act of the owner or occupant of any premises, the waste water, which under the above approved installation, does not enter the sanitary sewer system is caused to enter the sanitary sewer system, the premises shall be billed at the regular sewer service charge rates for all water used during the entire regular billing period in which the unlawful waste of water occurred, if it can be determined; otherwise for a period not to exceed five years in the discretion of the Board of Public Works.

The Common Council shall appropriate sufficient amounts and order paid the reasonable cost and value of the services rendered to the City of Ann Arbor by such Sewage Disposal Plant. Said value shall be determined in the same manner as hereinbefore established for private premises.

The latest information obtainable from Indiana shows that there are 67 sewage treatment plants in the state, 19 of which operate on the sewer rental basis. The sewer service charge in 15 of these 19 cities is based on the metered water consumption.

In Illinois there are 23 municipalities operating sewage treatment plants under sewer rental ordinances. Of these 23 municipalities, 12 base their sewer service rates on the water consumption. Wisconsin has 3 municipal sewage treatment plants operating under sewer rental ordinances, 2 on a flat-rate basis and the other on a fixed charge plus fifty per cent of the water bill. Several existing plants are considering sewer rental ordinances, and a number of new plants, now under construction, will use this method of financing.

Of the 73 municipalities in Michigan operating sewage treatment plants, 13 have sewer rental ordinances. The following table summarizes the practice in these municipalities.

	Basis of Charge
Alma	Volume of water consumed
Ann Arbor	" " " "
Battle Creek	" " " "
Caro	Flat rate per connection
Charlevoix	No report
Grand Haven	Volume of water consumed
Jackson	" " " "
Ludington	" " " "
Monroe	" " " "
Muskegon	" " " "
Muskegon Heights	" " " "
St. Ignace	No report
Traverse City	Volume of water consumed

You will note that 10 of the 11 cities reporting, base their charge on the volume of water consumed. This basis of charge seems to be the most popular and is the most practicable where the water consumption is metered and municipally owned.

The original Ann Arbor ordinance was passed August 10, 1934, but was amended December 17, 1937, before the rates were put into effect. I quote Section 7 of the ordinance, which, with proposed amendments, pertains to rates.

Section 7. The bills for services furnished by said Sewage Disposal Plant shall be levied upon each lot or parcel of land, building, or premises (hereinafter called premises) having any sewer connected with the sanitary sewer system, on the basis of the quantity of water used thereon or therein as the same is measured by the City of Ann Arbor Water Meter there in use. If any premises has any sewer connection with the sanitary sewer system, but is not a user of water which is measured by a City of Ann Arbor Water Meter, the quarterly charge shall be fixed by resolution of the Common Council. The Common Council of the City of Ann Arbor may classify the users of sewer service according to the quantity of water used, and charge such rates to the users in each class as it may deem reasonable.

Where it is evident that certain users of water use more water in the summer months for non-sprinkling purposes than they do in the winter months, the Common Council may order such users billed on the basis of water used in each month or each three-month period.

In cases where premises have a private water supply, the Common Council may order a water meter installed to measure the amount of water used in order to establish a basis for the sewage service charge, and the quarterly charge shall be fixed by resolution of the Common Council.

The bills for sanitary sewer services shall be prepared by the Water Department and collected at the same time and in the same manner as provided for water bills. The Water Department is hereby authorized to enforce the payment of such sewer service bills by shutting off the user's water supply, or an action of *assumpsit* may be instituted by the City against such user. Moreover, such bills for sanitary sewer services shall constitute a lien on the premises served by such a connection, and if not paid within ninety days may be certified to the City Assessor who shall place the same on the tax roll of the City. Such charges, so assessed, shall be collected in the same manner as general city taxes.

The rates to be charged for the sanitary sewer services are hereby fixed and determined to be as follows for each three-month period:

1. For the first 1,500 cu. ft. of water used 8.75 cents per 100 cu. ft.
2. For the next 98,500 cu. ft. of water used 5.25 cents per 100 cu. ft.
3. Over 100,000 cu. ft. of water used 3.50 cents per 100 cu. ft.
4. Minimum rate 75 cents, no discount.

7–5. Ten per cent discount allowed on all bills, except minimum rate paid within ten days from date of bill. Said rates shall be applied to the water billed on January first, February first, March first, April first, May first, and June first, except as herein provided. Billing on July first and October first shall be for the same amount as billed on April first, regardless of the amount of water used. Similarly the billing on August first and November first shall be for the same amount as billed on May first and the billing on September first and December first shall be for the same amount as billed on June first. Consumers billed for the first time in any month shall be charged at the established rates.

If any premises are billed for water on a monthly basis, they shall also be billed for sanitary sewer service on the same basis. The sanitary sewer service billing on the first of May, June, July, August, September, and October will be the same as billed on April first, unless application is made as provided in the next paragraph.

Nothing herein contained shall prevent the owner or occupant of any premises from electing to pay for sanitary sewer service on the basis of water used in every three-month period, provided such owner or occupant makes application in writing to pay on this basis for at least one year from the date of the next billing, following the date of application.

Nothing herein contained shall prevent any owner or occupant of a premises from making a division in the water service pipes, supplied with water through a single meter, so that, through the installation of one extra meter, the water used for purposes from which the waste water does not enter the sanitary sewer system can be measured separately from that water used for other purposes. No sanitary sewer service charge shall be made for such properly measured water used for purposes for which the waste water does not enter the sanitary sewer system.

When such a division of service is desired, application shall be made by the water consumer to the Board of Public Works, and when such division of service is certified to by the Plumbing Inspector and approved by the Board of Public Works, a meter, as above provided, shall be installed by the Water Department.

If by any act of the owner or occupant of any premises, the waste water, which under the above approved installation, does not enter the sanitary sewer system is caused to enter the sanitary sewer system, the premises shall be billed at the regular sewer service charge rates for all water used during the entire regular billing period in which the unlawful waste of water occurred, if it can be determined; otherwise for a period not to exceed five years in the discretion of the Board of Public Works.

The Common Council shall appropriate sufficient amounts and order paid the reasonable cost and value of the services rendered to the City of Ann Arbor by such Sewage Disposal Plant. Said value shall be determined in the same manner as hereinbefore established for private premises.

The Ann Arbor ordinance was designed to produce revenue equal to fifty per cent of the revenue received from metered water sales. As the rates are applied to water consumed in the six winter months, in order to eliminate water used for sprinkling from the sewer service charge, the sewer service rates are 57.85 per cent of the water rates, and produce revenue equal to 50 per cent of the total metered sales of water for the year.

Another point in the Ann Arbor ordinance is that the water user is given every opportunity to make his sewer service charge as low as possible so as not to curtail the use of water. If a consumer uses more water in the winter than in the summer, he may elect to pay the sanitary sewer service charge on the basis of water used in every three-month period. He may also apply for the installation of a meter for measuring water used for any purpose for which the waste water does not enter the sanitary sewer system. The charge to sewer users, who are not users of city water, is at present a flat rate, which is the average of the charge to families of the same size who are users of city water. We also have the privilege of installing a meter on the private water supply to determine the amount of water used.

The ordinance has been working very well, and although we have had some complaints, we have not had any refusal to pay the sewer service charge. This may be attributed to the fact that for the year previous to the time the sewage treatment plant was put into operation, the city water rates were increased 50 per cent for the purpose of providing funds for building a water softening plant. The sewer service rates were started the month after the 50 per cent increase in water rates was discontinued, so the water consumers' first bill for both water and sewer service was about the same as it had been the previous year for water alone. I believe the increase in the water rates for the year prior to the time the sewer rates were instituted was responsible for the sewer service charge being so favorably accepted.

The total accounts receivable (less municipal service charge), for the year the 50 per cent increase in rates was in effect, were $219,838.85. Of this amount only $686.99, or 0.31 per cent, has been charged off as uncollectable.

For the first thirteen months the sewer service charge has been in force, the accounts receivable were $77,900.91. The actual collections have been $76,804.82, leaving only $1,096.09 unpaid. On the basis of the Water Department's experience only 0.313 per cent of this amount, or $245, will have to be charged off as uncollectable, which I think is a remarkable record.

Sewer service is furnished to non-residents where existing sewers pass their property, at double the rates of residents, plus a minimum connecting charge of $66.

I am of the opinion that the charge based on the volume of water consumed is the fairest and most scientific. It is evident that this method cannot be used where the water system is not municipally owned or where the water services are not metered. One of the variations of

the flat rate basis of charge would most likely be the easiest to establish, but as stated before, I believe a rate based on the volume of water used and returned to the sanitary sewer system is the fairest basis of charge. Of course an ordinance, basing the charge on the volume of water consumed, in order not to curtail the use of water, should provide methods of eliminating any charge for water that does not enter the sanitary sewer system, such as water used for sprinking and water used in industry that is returned to the storm-sewer system or is used in manufactured products.

Reports from the cities contacted, indicate that sewer rental ordinances are working satisfactorily throughout the state and are providing a means of producing revenue for building and operating these necessary plants which, under existing conditions, could not be obtained from any other source.

The sewer service rates charged by Michigan cities are given in the following tabulation.

ALMA

Minimum charge per month (including first 2,000 gal. per month)	$.70
Charges per 1,000 gal. per month	
2,000 to 7,000 gal. per month	.20
7,000 to 17,000	.12
Over 17,000	.07

ANN ARBOR

Rates per quarter for 100 cu. ft.

Minimum charges	$.75 no discount
First 1,500 cu. ft. of water used	$.0875
1,500 to 100,000	.0525
Over 100,000	.035

Ten per cent discount on all bills except minimum if paid within ten days from date of bill.

BATTLE CREEK

Charges per 1,000 gal. per month

Minimum charge (including first 1,800 gal. per month)	$.30
1,800 to 15,000 gal. per month	.05
15,000 to 30,000	.03½
30,000 to 300,000	.03
300,000 to 400,000,000	.02½

CARO

Flat rate $2.00 per connection per year, assessed on regular tax roll.

GRAND HAVEN

Based on amount of water used in winter quarter

Quantity per Quarter	Monthly Charge
Up to 5,000 gal.	$ .50
6,000 to 10,000	.75
11,000 to 15,000	1.00
16,000 to 25,000	1.50
26,000 to 50,000	2.50
51,000 to 100,000	4.00
101,000 to 200,000	6.00
201,000 to 500,000	10.00
501,000 to 1,000,000	15.00
Over 1,000,000	25.00

Jackson

First	0–	300 cu. ft.	$1.60 per 1,000 cu. ft.
Next	300–	600	1.50
Next	600–	900	1.40
Next	900–	1,200	1.25
Next	1,200–	2,000	1.10
Next	2,000–	5,000	1.00
Next	5,000–	10,000	.80
Next	10,000–	25,000	.40
Next	25,000 and over		.22

Minimum Bills

$\frac{5}{8}$ in. meter	$ .50
$\frac{3}{4}$	.75
1	1.25
$1\frac{1}{4}$–$1\frac{1}{2}$	1.50
2	3.00
3	7.00
4	9.00
6	20.00
8	35.00

Sewage charges based on monthly meter readings and billed monthly and in accordance therewith; that sewage rates to domestic consumers be based on the average of monthly readings computed on the average consumption of water per month in the six months ending April 30 of each year, ten per cent discount if paid within fifteen days from date of bill.

Ludington

Minimum quarterly charge	$1.05
First 13,000 cu. ft.	$.07 per 100 cu. ft.
Over 13,000	.035 per 100

The above rates are applied to the water consumed in the quarter January to March. The other three quarters, the billing is the same as for the January to March quarter for residences. Factories are billed 70 per cent of March water bill and are billed monthly.

Monroe

Rate Schedule

First 400 cu. ft.		$0.58
Per 1,000 cu. ft., next	600 cu. ft.	1.26
Per 1,000	next 8,000	1.00
Per 1,000	next 85,000	.70
Per 1,000	next 94,000	.50

Minimum Bi-Monthly Bills

Meter Size		
$\frac{5}{8}$ in.	$0.58	Two paper mills charged at rate
$\frac{3}{4}$	0.87	of $4,000 per year per cubic
1	1.45	foot per second of industrial
$1\frac{1}{4}$	2.19	waste.
$1\frac{1}{2}$	2.57	Sewer users, not water users, are
2	3.69	charged a flat rate of $0.50 per
3	7.38	family for each billing period.
4	11.07	Each extra family in resi-
6	18.45	dence $0.25 per family.

Muskegon

Minimum charge per quarter including first 1,800 cu. ft. of water $1.00 and on all amounts over minimum shall be the following basis.

From 0 to 50,000 cu. ft. per quarter $.06 per 100 cu. ft.

From 50,000 to 100,000 cu. ft. $.05 per 100 cu. ft.

From 100,000 to 150,000 cu. ft. $.04 per 100 cu. ft.

All over 150,000 cu. ft. $.03 per 100 cu. ft., plus a 10 per cent penalty for delinquent accounts.

Such charges to be based upon average water consumed or used during the months of November to April, inclusive, of each year.

Muskegon Heights

0 to 5,000 gal. per month	$.09 per 1,000 gal.
5,000 to 10,000	.08
10,000 to 15,000	.06
15,000 gal. and above per month	.04

During the first week of each month each consumer is billed for a minimum charge of $1.10 for water and sewage services combined for that month. A discount of ten cents is allowed if the bill is paid before the 25th of the month. Each consumer is billed quarterly for the amount due in excess of the minimum. The sewage charge is based on the water consumed during the six winter months.

Traverse City

Minimum charge $1.50 per quarter

First 3,000 cu. ft. or part thereof per quarter	$0.80 per 1,000 cu. ft.
3,000 to 13,000 cu. ft. per quarter	.40
13,000 to 23,000	.20
Over 23,000	.10

Above rates apply to water consumed during the six winter months. The charge for residences for the first summer quarter is the same as for the preceding first winter quarter and the charge for the second summer quarter is the same as for the preceding second winter quarter.

Five per cent discount if bills are paid within fifteen days from end of each quarter.

Flint

The cost of operation of the sewage treatment plant is paid from water revenues.

St. Ignace

Minimum charge $.50 per month

First 4,000 gal.	$.25 per month plus meter service
Next 8,000	.20
Next 25,000	.15
Over 37,000	.10

Meter Service

⅝ in. and ¾ in.	$ .60 per month
1	1.00
1¼	1.25
1½	1.50
2	2.00

Meter readings obtained from the Edison Sault Electric Company.

ANN ARBOR

SEWAGE TREATMENT PLANT

Estimated Cost of Operation

1937–1938

Account				
16–140	Plant Expansion			
	Microscope	$140.00		
	Hot Air Sterilizer	32.00		
	Laboratory Desk	35.00		
	Lawn Mower	137.50		
	W. P. A. Grading, Etc.	984.00		
	Truck	923.50		
	Miscellaneous	200.00	$ 2,452	
16–205	Temporary Loan	$ 5,000		
16–605	Temporary Loan Interest	400	5,400	
16–225	Bonded Debt	13,000		
16–601	Interest Charges—Bonds	12,520		
	Interest Charges—Plus 10 per cent	2,552	28,072	
16–300	Sewage Treatment Service			$68,500
	Special Appropriation			984
16–408	Ferric Chloride		1,000	
16–409	Lime		1,000	
16–415	Miscellaneous		100	
16–420	Motor Equipment Operation		400	
	Motor Equipment Depreciation		200	
16–425	Power Purchased (At Plant)		5,000	
16–440	Salaries and Wages		15,480	
445				
446	Supplies		1,500	
450				
16–470	Power Purchased (Fuller St.)		450	
16–500	Auditing		300	
16–505	Billing (Payment to Water Dept.)		4,200	
510	Miscellaneous		100	
516	Office Expense (Plant)		50	
520	Telephone, Postage, Etc.		210	
16–430	Repairs of Plant Equipment (1½ per cent of $110,000.00)		1,650	
16–435	Repairs of Structures (½ per cent of $295,000.00)		1,475	
			$69,039	$69,484

It is possible that during the next fiscal year it will be necessary to construct auxiliary sludge drying beds and install chlorination equipment, which were omitted from the general construction contract.

ANN ARBOR CITY WATER DEPARTMENT

ANN ARBOR, MICHIGAN

No.....

Application

To Department of Public Works:

Application has been made in accordance with the provisions of the ordinance authorizing the construction and operation of a Trunk Line Sewer and Sewage Disposal Plant for the following service at

.....

Location

.....

I. For payment of sanitary sewer service on the basis of water used in every three-months period in accordance with Par. 3, Sec. 7

Applicant..... Signed by..... .....

Date

.....

II. For the installation of a meter for measuring water used for any purpose for which the waste water does not enter the sanitary sewer system, in accordance with Par. 4, Sec. 7

Purpose.....

Applicant..... Signed by..... .....

Date

Referred to Plumbing Inspector.

I hereby certify that none of the water supplied through meter No..... at the above location will normally enter the sanitary sewer system.

Signed..... .....

Plumbing Inspector Date

.....

III. To fix quarterly charge for sanitary sewer service on above premises where there is no city water service, in accordance with Par. 5, Sec. 7

Applicant..... Signed by..... .....

Date

Referred to Common Council.....

Date

Action..... .....

Date

.....

IV. Miscellaneous:.....

.....

.....

.....

Remarks:.....

Approved by

Board of Public Works..... Per..... .....

Date City Engineer

SLUDGE DIGESTION AND INSPECTION OF TANKS AT ROCKVILLE CENTRE, N. Y.*

By C. G. Andersen

Superintendent of Sewage Treatment, Rockville Centre, N. Y.

The digestion tanks of the Rockville Centre Sewage Treatment Works were recently completely emptied, cleaned and inspected. As these tanks were previously inspected seven years ago and have been operated continuously for eight years, the writer thought that some of the operating results and observations on the condition of the tanks might be of interest.

Description of Plant

The Rockville Centre Sewage Treatment Plant was designed by Clyde Potts, Consulting Engineer, and constructed in 1929. A previous design made in 1924 was of the same type, activated sludge with digestion of primary and activated sludge. At that time the digestion of activated sludge and even separate sludge digestion was somewhat novel. In the plant as constructed, provision was made for discharging sludge from the primary tanks and also from the secondary tanks to the sludge digestion tanks. The supernatant liquor was discharged to the influent of the primary sedimentation tanks.

The digestion tanks are of the suppressed roof type in which the water level in the tank may be maintained at an elevation slightly above the underside of the concrete tank roof. This prevents the drying out of floating solids or scum and provides for digestion throughout the entire tank contents. There are eight units of digestion tanks, each with a capacity of 7,950 cu. ft., making the total capacity 63,600 cu. ft. As the plant was designed for an ultimate population of 20,000 this is slightly more than 3 cu. ft. per capita. Each tank unit has a sludge inlet pipe and a supernatant or displaced liquor pipe, each of which is provided with a swivel joint so that the pipes may be swung up or down to adjust to the level of sludge discharge and liquor drawoff (Fig. 1). The ends of the pipes are attached to chains which pass through pipe sleeves in the roof. The tank bottoms have a slope of 12 per cent and drain to a digested sludge outlet. Each of the eight tanks has a gas collector which consists of an 18-in. flange pipe covered with a blank flange. The gas pipes are connected to the tops of the collectors and each collector has a scum breaker, which is a bent rod that may be worked up and down and rotated, to break up any scum that may collect in the gas collector (Fig. 2). The tanks are heated by hot water which is circulated through a closed piping system in the digestion tanks. The water is heated by gas obtained from sludge digestion. There

* Presented at the Tenth Annual Meeting of the New York State Sewage Works Association, New York City, January 21, 1938.

are 70 ft. of 2½ in. cast iron hot water pipe in each of the digestion units.

The gas collected from the sludge digestion tanks is carried to a 5,000 cu. ft. gas holder which supplies the blower house, where gas is

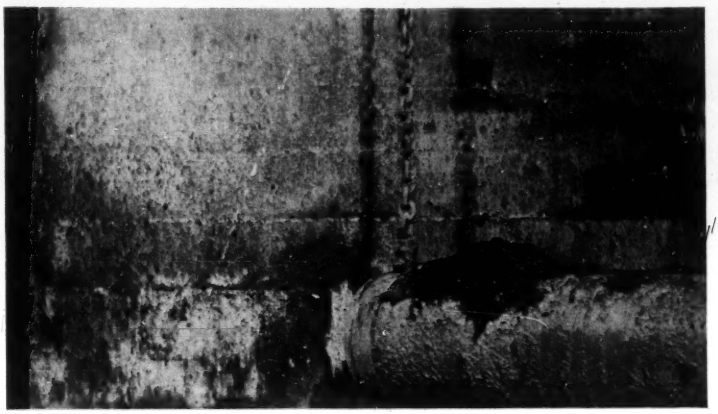


FIG. 1.—Swing pipe for removal of sludge or supernatant liquor.

used by hot water heaters and also by gas engines. One gas engine is connected to a generator and another to a blower. The tanks are designed so that the gas may also be collected in the tanks displacing the supernatant liquor as it forms. This procedure has not been followed.

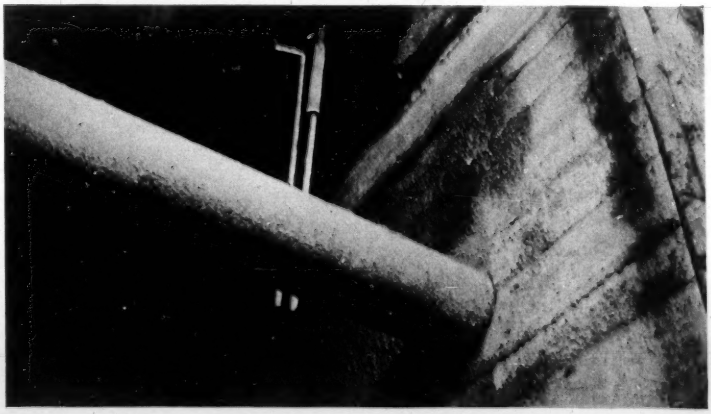


FIG. 2.—Manually operated scum breaker in gas collector.

Initial Operation of Digestion Tanks

When the tanks were first started in operation they were not seeded, but no difficulty was experienced at first. As house connections speeded up to the point where more than 60 per cent were connected, our troubles started. All the primary and excess activated sludge was discharged to the digestion tanks. In those days the activated sludge return was supposed to be about 20 per cent by volume and little attention was paid to the solid content of the sludge. As a result of the large quantity of sludge discharged to the digestion tanks the supernatant liquor was very strong and detrimental to the operation of both the primary and aeration tanks. The concentration of the excess activated sludge became a necessity, and as this procedure was perfected, the concentrated fresh sludge from the primary sedimentation tanks was mixed with the concentrated excess activated sludge in a separate chamber. This seemed to solve our problem as the quantity of sludge pumped to the tanks was greatly reduced and the quantity was controlled. With the assistance of heat in the digestion tank and with careful pH control the sludge was finally adjusted and a definite separation of sludge and supernatant liquor obtained, insuring a clear supernatant and removing one of our supposed reasons for bulking in the activated sludge plant.

Fig. 3.—Sampling sludge in digestion tank.

When the tanks were first started the production of gas was slow and gas furnished by the local gas company was used for three months—January, February and March, 1931. Following this initial warming up of the tanks they proceeded under their own steam and from then on, no purchased gas has been used. From the beginning of operation the tanks have been carefully observed and a considerable

volume of data obtained. The temperature and depths of sludge in the tanks were taken daily by a cross-section sampling pole (Fig. 3). This sampling device consisted of a pole on which a number of bottles were fastened at intervals of one foot. The pole is inserted to the full depth of the tank and starting at the top the stoppers are removed one at a time by cords fastened to them. This sampling was done daily for about a year and weekly thereafter.

Operation of Digestion Tanks

The same principles used in establishing the operation of the activated sludge tanks have been applied to the operation of the sludge digestion tanks. As described in a previous paper, the plant is considered as a living organism. This is notably true in the case of the digestion tank. It is my opinion that the best results are obtained from a digestion tank when sludge is admitted and withdrawn from a tank as uniformly and as continuously as possible.

Sludge is added to each tank daily. In adding sludge, consideration is given to the quantity of ripe sludge in the tanks so that the quantity of fresh solids added is not too great in proportion to the quantity of digested sludge. At first we added approximately 2 per cent of fresh solids to digested sludge on the basis of organic matter but we have since increased this to as much as 6 per cent. The sludge admitted to the tanks has previously been concentrated by adding concentrated primary sludge to concentrated activated sludge, which may have as much as 2 per cent solids. I believe that the mixing of these two sludges and allowing them to stand for a time is of advantage not only in concentrating solids but also in adjusting the organisms so that the aerobic organisms are reduced and anaerobic action started. Whereas we formerly added as much as 6,000 cu. ft. of sludge per day to the digestion tanks we now add only 1,600 cu. ft. of the concentrated sludge. The advantages of reducing the quantity of sludge added to the tanks and consequently reducing the quantity of supernatant liquor returned to the treatment process and the quantity of heat required to maintain the desired temperature in the digestion tanks are obvious.

Hydrated lime is added to the sludge discharged into the digestion tanks. Three hundred to four hundred pounds of lime are used to 1,600 cu. ft. of 2.96 per cent sludge. This procedure, together with the turning over and liming of each tank every eight weeks, has kept our pH value very steady, 7.1 to 7.3 for the last seven years. I have found it better to add lime to the sludge as it is pumped to the tanks rather than to try to adjust the pH of the contents of an entire tank after the sludge has gotten out of control. While many engineers and operators maintain that it is not necessary to add lime to a digestion tank after the proper pH has been obtained I have found that at Rockville Centre the addition of lime is advantageous. Possibly with larger digestion capacity it would not be necessary to add lime. We turn over a tank at least once every eight weeks during the winter months. This is done

by pumping sludge out of a unit and returning the same sludge to the unit. While this is being done 500 pounds of lime is added to 60,000 gallons, of which approximately 50 per cent is sludge. This is not done during the period from May to November.

When pumping sludge to the tanks equal amounts are pumped to each tank. The quantity of seeded sludge in the tanks is known and the amount added is adjusted so that the rate of application of fresh sludge is 2 to 5 per cent, and at present more than 5 per cent, of the amount of seeded sludge. This is based on organic matter in the sludge. At present only about 50 per cent of the tank capacity is made up of sludge and the remainder is supernatant liquor. We have found it best to have the sludge inlet pipe at its lowest position and the supernatant liquor pipe at its highest position. Sludge is withdrawn uniformly throughout the year, twice monthly. Withdrawals are controlled by the depth of sludge in the tank. Care is taken to leave nine feet of sludge in the tank at all times to maintain the sludge balance.

The temperature of the sludge in the digestion tanks has been maintained in winter at a minimum of 68 deg. F. In summer the temperature rises to 85 to 90 degrees. The average annual temperature is about 78 degrees.

The quantity of sludge discharged to the digestion tanks is known with considerable accuracy. Sludge from the primary and secondary tanks is allowed to concentrate in a chamber and 1,600 cu. ft. of this concentrated sludge is added to the tanks each day. This amount is determined by the depth of sludge drawn from the concentration tank so it is therefore an exact volume. The per cent solids of this sludge is determined daily so from these results the weight of dry solids admitted to the digestion tanks may be computed. The average of all the determinations for the year 1936 show that 1,530 pounds of dry solids per million gallons of sewage were discharged to the digestion tanks.

The amount of dry solids may also be computed from the suspended solids removed by treatment, as follows:

Raw sewage	214 p.p.m. suspended solids	
Primary effluent	112 " " "	
Removed by primary tanks	102 p.p.m. suspended solids	= 850 lbs. per m.g.
Removed by secondary tanks—		
Primary tank effluent	112 p.p.m. suspended solids	
Secondary tank effluent	42 " " "	
Removed	70 p.p.m. suspended solids	= 585 lbs. per m.g.
		1,435 lbs. per m.g.

This checks closely with the figures of 1,530 pounds per million gallons computed from the actual quantity and solids content of sludge.

There is an additional removal of solids by the clarifying filters which reduce the suspended solids from 42 p.p.m. in the secondary tank effluent to 11 p.p.m. in the filter effluent. This reduction of 31 p.p.m., or 258 pounds per million gallons, is disposed of as filter cake and does not go to the digestion tanks.

As frequent determinations are made of the volatile and ash content of the digested and undigested sludge, the pounds of sludge digested may be computed. The 1,530 pounds per m.g. of undigested sludge averaged 30.5 per cent ash, equal to 467 pounds per m.g. Using this amount of ash the total weight of digested sludge with 49.75 per cent ash is 939 pounds per m.g. The reduction of solids by digestion was therefore—

1530 lbs. per m.g. undigested sludge
939 lbs. per m.g. digested sludge

591 lbs. per mg. digested

If the 939 pounds per m.g. of digested sludge is dried to 40.92 per cent solids, the average for the year, the volume would approximate 36 cu. ft. of dried sludge per m.g. The average reported quantity for the year based on actual measurements of dried sludge was 31 cu. ft. per m.g.

Table I gives data on the solids content of sludge added to and drawn from tanks. The solids content of the sludge in the tanks averaged 3.5 per cent, with volatile content of 50 to 52 per cent.

TABLE I.—*Sludge Record—1936*

Month	Undigested Sludge			Digested Sludge			Dried Sludge	
	Per Cent Solids	Per Cent Vol.	Per Cent Ash	Per Cent Solids	Per Cent Vol.	Per Cent Ash	Per Cent Solids	Per Cent Ash
Jan.	2.6	68	32	3.3	55	45	20	49
Feb.	2.7	66	34	3.8	54	46	25	52
March	3.6	66	34	3.1	48	52	23	58
April	4.3	73	27	3.4	47	53	54	43
May	3.6	72	28	3.9	54	46	39	54
June	2.6	68	32	4.9	53	47	54	51
July	2.3	66	34	5.7	48	52	55	53
Aug.	2.2	68	32	5.7	48	52	57	55
Sept.	3.6	72	28	5.3	42	58	79	55
Oct.	2.5	71	29	5.3	48	52	44	57
Nov.	2.6	75	25	4.5	52	48	23	49
Dec.	2.9	69	31	4.2	54	46	18	59
Average	2.96	69.5	30.5	4.42	50.25	49.75	40.92	52.93

It is generally supposed that supernatant liquor from a sludge digestion tank is very foul and high in B.O.D. By the method of operation described, the B.O.D. of the supernatant liquor at Rockville Centre has remained fairly uniform, ranging from 200 to 1,200 p.p.m. B.O.D. The suspended solids content averaged 850 p.p.m. As the quantity of supernatant liquor is small, averaging only 1,600 cu. ft. or 12,800 gallons per day, the load on the plant from this source is not serious. It is my opinion that with careful control of the sludge digestion process,

rather than by haphazard methods, a good supernatant and well digested sludge may be efficiently produced.

Inspection of Sludge Digestion Tanks

After seven years of operation, the writer thought it wise to inspect the digestion tanks; in fact, it should have been done much sooner. It was desired to know what was happening to the concrete, iron work, and piping in the tank, and what the sludge would look like as a whole. We had previously inspected the gas lines and found no indication of deterioration in strength found at some other plants. The procedure was as follows:

The gas was cut off from the gasometer and let out to the atmosphere. The tank was pumped full, thereby completely forcing out all gas. A part of the sludge was then drawn off to another tank to be used again when the tank was placed in operation. After this drawing, the remainder of the sludge was pumped to the sludge drying beds. As the sludge level was lowered, tests were made of the strength of the gas in the tank by a flame testing lamp. Apparently, gas was not very concentrated, for no indications of inflammability were noticed. A fan was installed to expell all vapor and gasses from the tank. During the inspection of the tank, the safety lamp was used to check the inflammability of the gas. A regular Davis gas mask with canister, recommended for sludge gas, was used at first (Fig. 4) but as the vapor

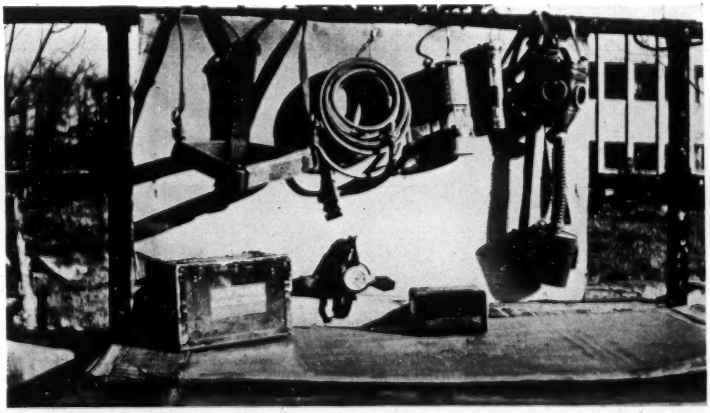


Fig. 4.—Instruments used in tank inspection. Safety harness with non-sparking metal, flashlight passed by Underwriters, safety lamp and tubing and gas masks.

from the warm sludge and gasses disappeared, a small nose type of cartridge respirator was used (Fig. 4). This gave better vision for inspection. A hose mask with hose extending outside the tank would

be better than the canister type. If hose lengths of 50 ft. or more are necessary, it is advisable to use a pump. If it is impractical to ventilate the tank thoroughly, the hose mask should certainly be used.

As the tank contents were lowered, a crust or scum was noticed which was found to be about 10 inches thick. This was made up of very light material, a mixture containing all sorts of fibrous, cellulose material, seeds, and similar matter. A sample taken showed this scum to contain 48 per cent volatile content and 52 per cent ash. Considering the fact that the tank had not been completely cleaned for eight years, we concluded that while a certain amount of material floats, it is also continuously breaking down and digesting, or the accumulation of scum would have stopped the operation of the tank. At our plant, we find we are handling a very large amount of concentrated organic matter, practically garbage in appearance and makeup, that collects in our pump station wet well. The wet wells are cleaned daily, and this material is flushed into the pumps. The load is very noticeable when it reaches the plant, showing 60 to 80 c.c. per liter, with average of 30 c.c. per liter in an Imhoff cone. This high concentration lasts for about three hours daily.

The moving of all this concentrated material daily from the pumping station to the plant proves that it can be readily transported, and settling tests also show that most of it settles rapidly. When the raw sewage with settleable solids of 40 to 80 c.c. per liter is being added to the primary tanks, the effluent shows only 5.7 c.c. per liter. This material that settles in the primary tanks of course goes to the digestion tanks daily with the other sludge. The inspection proved that this material digested in the tanks. During the cleaning some difficulty was experienced with the sludge pump when this fibrous material got under the check valves, causing them to unseat. In drawing off the sludge, as the contents reached the bottom, the supernatant liquor and lighter material having run off first the heavier sludge and this fibrous floating layer had to be broken up. As this was broken up and pumped off, a mass of heavy material was found to have formed a perfect filler in this corner under the inlet pipe. Inspection showed that it consisted mostly of inert material, grit, sand, non-organic material with ash content of 78 per cent. This grit was not pumped out but was removed by buckets.

The inspection of the tank showed the inside piping in surprisingly good condition (Fig. 5). The concrete was in very good condition, with no sign of disintegration. The pipes had not corroded and bolts fastening the supports for the heating coils were as firm as when placed. Chains, steps and other iron parts were in very good condition. There was about $\frac{3}{16}$ in. of scale on the heating pipes in some places. This scale appeared to be of iron oxide when first noticed but was found to be made up largely of lime. In spite of this scale no appreciable reduction in the effectiveness of the coils for heating or insulation action of the scale has been noticed. The tank was left out of service and after

FIG. 5.—Condition of interior of tank.

drying out over night the scale came off very easily. Even though conditions in the tanks were found to be very good, the writer feels that good operation calls for an inspection of a tank of this type at least once every three years. By doing this, long tie-ups of tanks can be avoided. Only three days were required to clean, inspect and put the tank back into service. If done more frequently the time required for cleaning would be greatly reduced.

SUMMARY

An inspection of a fixed-cover sludge digestion tank after more than eight years of continuous service showed concrete and iron work inside the tank to be in good condition. Some lime scale on heating pipes was easily removed.

The small quantity of scum found showed that good digestion had been obtained throughout the tank. In operating sludge digestion tanks, careful adjustment of the ratio of fresh solids to digested sludge, control of pH, and regular systematic operation will insure good results. Allowing a mass to accumulate in a tank for a large community will only lead to the old well known sayings—"Tanks are foaming," "rolling over," "bacterial action is bad," "more tanks are needed," etc. Such conditions cause the process of sludge digestion to lose prestige.

SLUDGE DRYING ON OPEN AND COVERED DRYING BEDS *

By Lewis V. Carpenter

Prof. of Sanitary Engineering, N. Y. University

Drying of sludge on sand beds has been practiced in the United States since the first Cameron septic tank was constructed. Later the open beds were found to be limited in capacity in the northern climates and special types of glass covers were adopted so that the beds would be protected from the weather. Various State Departments of Health set up regulations governing the area of sand drying bed required for open beds and in most cases they require one-half that area for glass-covered beds. The purpose of this paper is to present data collected from various Long Island plants where sludge is dried on glass-covered beds, and to describe experiments on specially constructed beds for filtration of sludge.

Periodic visits were made to four sewage treatment plants on Long Island and, in cooperation with the operator, samples of sludge were collected from the drying beds at the time of pouring of sludge and each day thereafter until the sludge was removed from the bed. These samples were collected in 140 c.c. glass-stoppered bottles and taken to the laboratories of New York University for analysis. Care was taken to free the sample from adhering particles of sand. At the time the sludge was poured on the bed, a 2-liter sample was collected for complete analysis.

The analysis of the sludge, as poured, included alkalinity, pH, specific gravity, moisture content, and solids (fixed and volatile). The drainability of wet sludge was determined by the method of Babbitt and Schlenz (1). A volume of 615 c.c. of standard Ottawa sand was heated to drive off all moisture and then cooled. The sand was placed in a sieve with thirty meshes to the inch. This volume of sand made a layer about ¾ in. deep. A one-liter sample of the sludge was placed on the sand and the amount of liquor that drained off was measured.

The drying of sludge can be broken down into two processes, drainage and evaporation. The first of these is a sedimentation process involving the hydrodynamics of mixed phases flowing through a porous medium. The fluid is composed of liquid and solid suspension phases and the porosity of the medium changes as the flow continues. The hydromotive force is the difference between the gravitational head and the purely molecular forces involved in capillary action. As sedimentation proceeds the size of the pores through which the flow takes place decreases, and the effect of molecular forces increases. At the same time viscous resistance increases so that the rate of flow drops off rapidly as drainage proceeds. The drainage phase can be improved by using a shallower sand bed and providing free under-drainage. It

* Presented at the Long Island Section Meeting, Freeport, L. I., March 25, 1938.

has been suggested that possibly air bubbled up through the sludge would form a temporary liquid filament through which the rate of flow would be increased.

The evaporation process can be broken down into two parts, the actual evaporation from the bed and the removal of the moist air. The evaporation itself depends on two factors, the heat balance for the bed as a whole and the relative vapor densities corresponding to saturation at the temperature of the bed and to that layer of air above the bed. Thermal equilibrium will be established when the internal temperature has risen to the point that the heat losses plus the heat required for evaporation equals the heat input. The heat input at any instant depends on the solar constant, the area of the bed, the angle of the sun with the bed and the various absorption factors due to atmospheric conditions and the nature of the glass used in the covered bed. The heat losses will be due to radiation, conduction and convection.

A series of tests in the laboratory indicated that with free underdrainage and a shallow sand bed, the efficiency of drainage could be greatly increased. Laboratory tests on drainability using 1 inch of sand (passing 14 and retained on 28) showed the following:

Town	Treatment	Initial Moisture, Per Cent	Drainability 12 Hrs. Reduction, Per Cent
Huntington	Heated separate digestion	92.9	8
Rockville Centre	Digested activated sludge	94.0	14
Great Neck	Imhoff	95.8	17
Port Washington	Imhoff	96.2	22

The depth of sludge on the sand, temperature, and relative humidity were the same in all cases. These data indicate that the higher the initial water content of the sludge, the larger percentage of water is removed by draining. If the sludge is properly digested and of a low initial water content, the drainability is not as important as with an improperly digested sludge.

The laboratory drainability test was made on all samples of wet sludge. Figure 1 shows the relative rates of draining in per cent of total drainable liquor. The drainability test results indicated that a greater reduction in moisture could be accomplished in a much shorter time if the sludge beds were constructed so that they would have bottom ventilation. Three filters, each with 4 sq. ft. area, were constructed (Figure 2). They were set 12 in. from the floor and the sand was placed on a 30-mesh brass screen which was supported on a ¼ in. galvanized netting. The sand from the large filter was used in the small filters. The small filters were placed on the floor of the glass covered sludge drying beds at Port Washington. One filter was placed in the center of the bed and one at each end.

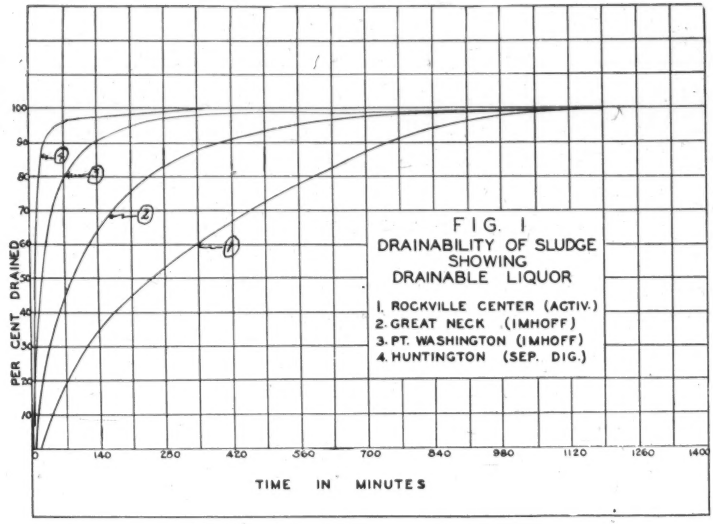


FIG. 1.

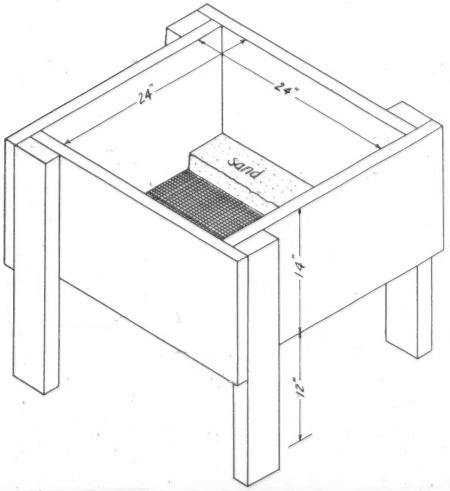


FIG. 2.—Experimental filter boxes.

Sludge was poured in the filter boxes to the same depth as on the large bed. For the first three runs, the depth of sand in the boxes was 4 in. then the depth of sand was cut to 2 in. Samples of sludge were taken daily from the box and from the bed in the immediate vicinity of the boxes. Figure 3 shows the average determinations for a set

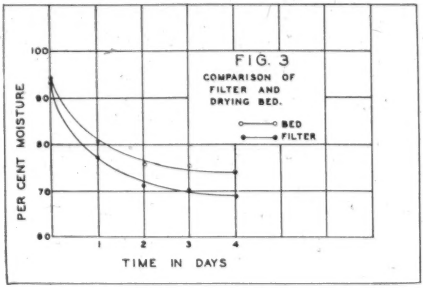


FIG. 3.

of six tests. These experiments indicate:

1. When a sand depth of 2 in. is used on the filter, this type of bed will dry the same depth of sludge in one-half the time necessary with ordinary beds.

2. In all of these experiments, the filters were placed on top of the wet sludge of the drying bed. The air immediately below the bottom of the filter was usually saturated with moisture. Laboratory results indicate that the filters would have been more efficient if the filters had been set on a dry rather than a wet surface.

3. This type of filter does not appear economically feasible with the existing glass-covered beds but could be easily adapted to a bed discussed later in the paper.

TABLE I

	Great Neck Sewer District		Port Washington		Huntington		Rockville Centre	
	Sludge as Applied to Beds	Sludge as Removed	Sludge as Applied to Beds	Sludge as Removed	Sludge as Applied to Beds	Sludge as Removed	Sludge as Applied to Beds	Sludge as Removed
Total volume, cu. ft.	8,899	2,586	22,506	6,624	17,700	7,050	4,553	1,899
Specific gravity	1.029	1.079	1.024	1.054	1.05		1.021	
pH	7.3		7.1		7.6		7.4	
Moisture per cent	95.5	67.7	95.3	74.00	91.6	73.0	94.6	75.5
Volatile solids per cent	55.6	52.6	64.9	59.4	51.4	49.9	57.6	56.6
Depth—inches	8.0	2.4	7.2	2.9	10	4.3	5.0	2.0
Drying time—days	—	28		6.75		12.3		6.3
Loading solids, lbs. sq. ft. year	21.5		22.7		43.3		19.0	
Type	Imhoff		Imhoff		Heated separate sludge		Activated sludge digested in heated tanks	

One of the difficulties in comparing actual time necessary to dry sludge is the various operators' ideas as to when sludge should be removed from the beds. Four plants were included in this study. One plant would not remove sludge from the beds until the moisture content was about 65 per cent, with about 30 days drying time, while another plant removed the sludge with a moisture content of around 75 per cent and a drying time of less than 10 days. The general characteristics of sludge drying are shown for the four plants in Table I. The plants of the Great Neck Sewer District and Port Washington have Imhoff tanks, and the moisture content of the sludge is about 95 per cent. Great Neck had an average drying time of 28 days and Port Washington 6.75 days while the load of solids, lb. per sq. ft. per year, was 21.5 and 22.7.

Great Neck

The Great Neck sewage treatment plant was rebuilt in 1929. It serves 6500 persons of the Great Neck Sewer District, which has a separate sewerage system with an average flow of 1.0 m.g.d. The sewage is pumped and flows through hand-cleaned racks with parallel bars spaced 2 in. on centers. The sewage is pre-chlorinated and then flows through two covered Imhoff tanks which operate in parallel, with an average detention period of 1.0 hour. The depth of the tanks from flow-line to sump is 32 ft. and the gas is allowed to waste through the gas vents.

Table II.—*Sludge Drying at Great Neck Sewer District*

Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture
0	95.0	0	95.8	0	96.1	0	97.1	0	95.4
3	82.4	3	84.8	4	84.2	3	83.8	4	78.2
6	78.3	6	82.3	7	83.8	7	81.8	7	74.6
9	77.2	9	81.2	11	82.9	10	80.2	11	63.3
12	79.4	12	81.1	14	80.0	13	74.2		
15	77.9	15	78.5	18	79.2	17	66.8		
19	72.6	19	76.6	21	78.4				
22	70.4	22	75.3	28	77.9				
26	68.0	26	72.8	32	72.4				
30	65.9	29	69.6	36	69.1				
33	65.9	40	67.0	39	69.0				
Ave. temp.	43.5° F.		29.9° F.		29.9° F.		47.2° F.		78.0° F.

The sludge is pumped from the Imhoff tanks by air-lift to either of two glass-covered beds or the open beds. The one covered bed has 2000 and the other 1200 sq. ft. of sand area. The one open bed has 2346 and the other 1551 sq. ft. of sand area. The underdrain system consists of 5-in. terra cotta drain tile covered with 15 in. of gravel and 6

in. of sand with an effective size of 0.285 mm., and a uniformity coefficient of 2.3.

FIG. 4.—Sludge on bed for 24 days at Great Neck Sewer District, Long Island.

When the average outside temperature was 78° F. the sludge was dried to 63.3 per cent moisture in 11 days while when the average temperature was 29.9° F. it was dried to 69.0 per cent moisture and removed from the bed partially frozen.

The data show the following:

Great Neck, Long Island

Area of glass covered sand beds	3200 sq. ft.
Contributing population	6500
Area of bed (sq. ft. per capita)	0.5
Bed No. 1—area 1206 sq. ft. empty	39.1% over 8-month period
Bed No. 2—area 2000 sq. ft. empty	53.0% over 8-month period
Lb. dry solids per sq. ft. of bed dried during 8-month period	14.3
Lb. dry solids per capita per period	7.1

If beds were utilized to their full capacity, 98,000 lb. of dry solids could be dried.

PORT WASHINGTON, LONG ISLAND

The Port Washington sewage treatment plant serves a population of 10,000 (1930 census), using a separate system with an average daily flow of 750,000 gallons. The sewage is pumped and flows through hand-cleaned racks with parallel bars spaced 1½ in. on centers. The sewage

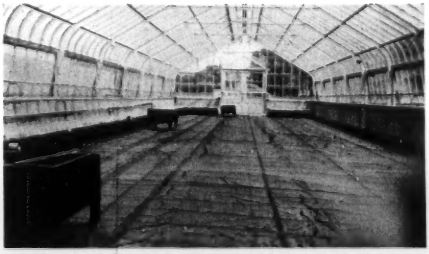


FIG. 5.—Sludge on bed 7 days at Port Washington, L. I. Note the three experimental filters.

is pre-chlorinated and then flows through two covered Imhoff tanks which operate in parallel, with an average detention period of 2 hours. The depth of the tanks from the flow line to sump is 21 ft. and the gas is allowed to waste through the gas vents.

The sludge is pumped from the tanks by air-lift pumps to one of two glass-covered sludge drying beds. One bed has 3220 and the other 2230 sq. ft. of sand area. The underdrain system consists of 5 in. terra cotta drain tile covered with 9 in. of graded gravel and 9 in. of sand with an effective size of 0.235 mm. and a uniformity coefficient of 3.7.

Table III shows some typical data collected on drying.

TABLE III.—*Sludge Drying at Port Washington*

Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture
0	95.8	0	95.0	0	95.4	0	94.7	0	96.3
3	81.6	3	84.5	3	85.0	3	84.2	3	83.4
6	81.4	8	69.7	6	81.6	6	82.2	6	82.4
10	75.4			10	76.3	9	71.7	9	78.4
Ave. temp.		70.3° F.		57.7° F.		54.4° F.		82.3° F.	

Port Washington, L. I.

Area of glass covered sand beds	5450 sq. ft.
Contributing population	10,000
Area of bed (sq. ft. per capita)	0.55
Bed No. 1—area 2230 sq. ft. empty	80.9% of time
Bed No. 2—area 3220 sq. ft. empty	84.3% of time
Lb. dry solids per sq. ft. of bed dried during year	22.7
Lb. dry solids per capita; actually dried	12.4

If beds were utilized to full capacity, 727,000 lbs. of dry solids could be dried per year.

HUNTINGTON, L. I.

The plant at Huntington was built in 1933. It serves 10,000 persons. The sewerage system is separate, with an average daily flow of 750,000 gallons. The sewage is pumped and flows through hand-cleaned racks with parallel bars spaced on 2 in. centers. The sewage is pre-chlorinated (during summer months) and flows to sedimentation tanks which have 1½ hours detention period, based on the average flow. The sludge is removed daily by a Link Belt sludge collector and pumped to a heated digestion tank which is maintained at a temperature of 85° F. The digester is equipped with a floating cover for gas collection, the gas being utilized for heating the digester and some of the buildings. The sludge flows by gravity from the digester to the glass-covered sludge drying beds. There is one large cover over four separate drying beds, each with 1200 sq. ft. of sand area. The underdrain consists of 4-in. open jointed tile laterals and a 6-in. tile manifold

FIG. 6.—Sludge on bed 21 days at Huntington, L. I., June 24, 1936.

covered with 6 in. of graded gravel and 12 in. of sand with an effective size of 0.313 mm. and a uniformity coefficient of 2.85.

Data on typical drying records are shown in Table IV.

TABLE IV.—*Sludge Drying at Huntington*

Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture
0	92.1	0	92.9	0	92.4	0	90.5	0	89.8
3	79.9	3	82.6	1	82.4	1	80.6	1	79.2
6	76.8	6	80.5	2	81.4	2	79.2	2	79.2
9	74.5	9	79.8	3	81.0	3	75.2	3	78.4
12	71.1	12	78.8	6	73.8	6	74.9	4	
15	70.0	15	78.3	9	73.7	9	68.5	5	74.5
		21	78.0			13	68.5	6	74.2
Ave. temp.	61.0° F.	35.2° F.		55.1° F.		76.5° F.		78.5° F.	

Huntington, L. I.

Area of glass covered sand beds	4800 sq. ft.
Contributing population	10,000
Area of bed (sq. ft. per capita)	0.48
Bed empty	60.5% of time
Lb. dry solids per sq. ft. of bed dried during the year	43.3
Lb. dry solids per capita	20.8

If beds were utilized to capacity 525,000 lbs. of dry solids could be dried per year.

ROCKVILLE CENTRE

The Rockville Centre (population 20,000) sewage treatment plant was built in 1929 and serves that town, which has a separate sewerage system with an average daily flow of 1,500,000 gallons. The sewage is pumped to the primary settling tanks, which are equipped with mechanical sludge collectors and the detention period is 1 hour. The clarified sewage flows to the aeration tanks where it is aerated 5 to 6 hours. The secondary settling tanks provide a detention period of 1

hour. The sludge from the primary and secondary tanks is pumped to heated digesters. The sludge from the digesters is pumped to one of the sand beds, of which there are seven, all under one large glass cover. Each bed has 2850 sq. ft. of sand area. The underdrain system consists of 6-in. tile drains covered with 9 in. of graded gravel and 12 in. of sand with an effective size of .313 mm. and a uniformity coefficient of 2.85.

TABLE V.—*Sludge Drying at Rockville Centre*

Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture	Days on Bed	Per Cent Moisture
0	94.3	0	93.9	0	95.7	0	94.6
1	84.7	2	87.6	1	86.2	1	92.8
		3	87.0	2	81.0	2	88.8
3	70.8	4	77.4	3	79.9	3	86.4
4	71.0	5	80.2	4	77.2	4	83.1
5	68.5	6	75.3	5	75.0	5	85.3
6	67.2					6	85.2
7	66.4						
Ave. temp.	58° F.	58.5° F.		45.3° F.		41.3° F.	

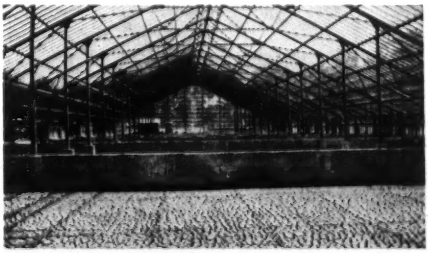


FIG. 7.—Covered sludge bed at Rockville Centre, L. I., August, 1936.

Data were collected for a period of several months and typical drying records are given in Table V. Enough data were not collected to make the summaries as made for the other three plants.

The experimental data indicate that the beds at the three Long Island plants could be used for a much larger population than their designed value of approximately 0.5 sq. ft. of bed area per capita. If the sludge is removed from the beds when the moisture content is near 75 per cent it would be possible to dry sludge satisfactorily at these plants with an area of not over 0.25 sq. ft. of glass-covered beds per capita. It is interesting to note that the beds were not in use 50 per cent of the time.

TABLE VI.—*Sludge Drying at Typical Plants*

Plant	Pounds of Dry Solids per Sq. Ft. of Bed/Yr.	Pounds of Dry Solids per Capita per Year
Huntington, L. I., N. Y.	43.3	20.8
Port Washington, N. Y.	22.7	12.4
Great Neck, N. Y.	14.3*	7.1*
Akron, Ohio	26.7	16.9
Dayton, Ohio	52.5	21.8
Marion, Ohio	62.0	19.2
Elyria, Ohio	30.0	14.1

* 6 months period.

ACKNOWLEDGMENT

The experimental work reported in this paper was done by Walter Schaefer, research fellow of the fellowship established by Lord and Burnham Company.

Part of the laboratory work was done by workers of project 165–97–6025 of the Research and Statistical Division of the Works Progress Administration for New York City.

BIBLIOGRAPHY

Babbitt, Harold and Schlenz, Harry, University of Illinois *Bulletin*, **198**, page 21 (1930).

JACKSON, MICHIGAN, SEWAGE PLANT OPERATION

By R. B. Jackson and R. A. Greene

Chief Operator, and Assistant Superintendent Chemist

The Jackson, Michigan, plant was placed in partial operation in December, 1936, and total treatment was started in March, 1937. It was designed by the Fargo Engineering Company of Jackson, and George B. Gascoigne and Associates of Cleveland and New York City.

The city is served by combined sewers so that the flow reaching the plant is subject to extreme fluctuations, varying from 2 to 12 m.g.d., with hourly fluctuations between 2 and 30 m.g.d.

When the plant was placed in service, only primary treatment was practiced the first month; beginning early in February, 1937, the secondary process was gradually started, and by the first of May, the entire plant was in active operation. The first digested sludge was drawn to the glass covered sludge beds late in June.

An aerial view of the plant is shown in Fig. 1 on page 514.

Some of the features of operation are discussed in the following papers.

BREAKDOWN OF POWER REQUIREMENTS

By R. B. Jackson, *Chief Operator*

This report is for the period of July, 1937, to February, 1938. It is one of our progress reports and it is intended to continue this investigation until we are able to operate our equipment most efficiently. The policy that has been established at Jackson is that the plant has been built to treat sewage and it should be operated as efficiently as possible, but treatment should not be sacrificed for economy.

The data shown in Table I are based on the daily readings of meters that measure the electric power to the various mechanical devices and the flow of sewage, air and sludge to the different tanks. The plant has a connected load of 870 horsepower, but only requires between 250 to 350 H.P. daily. The average daily flow has been 6.4 m.g.d. or about one-half of the plant's capacity. The average monthly amount of power used throughout the plant is 133,200 kwh., or 693 kwh. per million gallons of sewage treated. The electrical energy used for primary treatment, which includes all of the lighting, the raw and excess sludge pumping is 55 kwh. per million gallons. The secondary part of the plant requires 638 kwh. per million gallons. This figure includes the pumping of the settled sewage and the return sludge against a 11 ft. head. The data show that 92 per cent of the power is used for secondary treatment. The electrical energy which is used for the secondary part of the plant is consumed by three 15 HP. variable speed motors which pump the settled sewage into the aeration tanks; by a 150 HP.

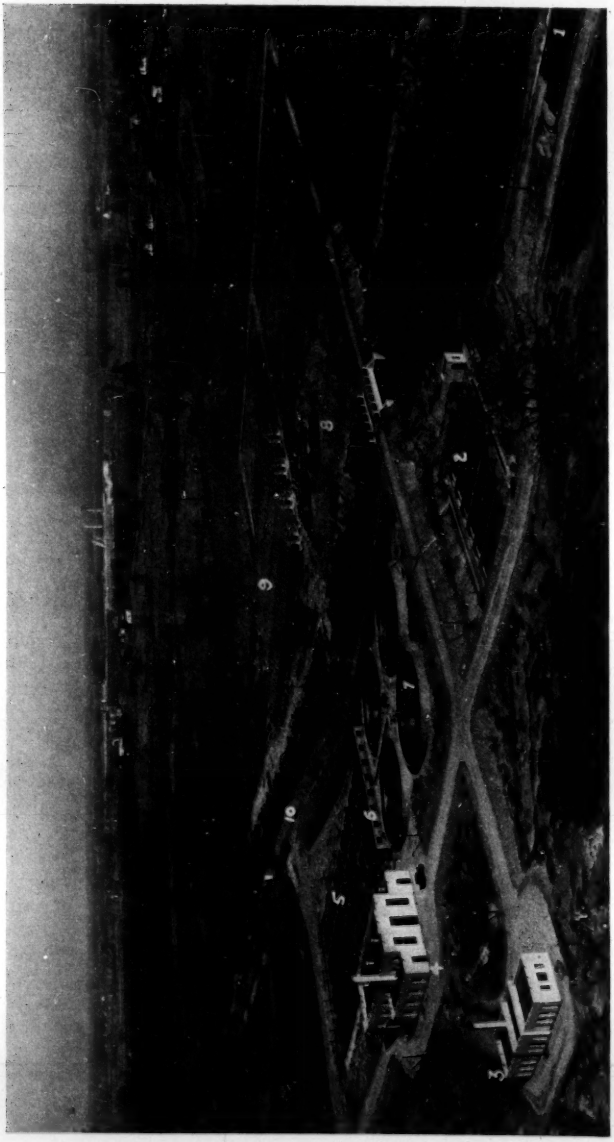


Fig. 1.—Aerial view of the Jackson Sewage Treatment Plant.

TABLE I.—*Operating Records and Comparison of Power Units, Jackson Sewage Treatment Plant*

Period	Raw Sewage M.g.d.	Cu. Ft. Air per Gal.	Aeration Period Hr.	Return Sl. M.g.d.	Suspended Solids P.p.m.		5-Day B.O.D. P.p.m.				Total HP. per M.g.	Blowers and Aerators			
					Raw	Final	Raw	Settled	Final	Lb. per Day Removed		Lb. B.O.D. Removed per Day by Aeration	Kwh. per Day	Lb. B.O.D. Removed per Kwh.	HP. per M.g.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1937															
Aug.	7.40	0.8	8.1	0.73	161	15	88	48	0.8	5378	37.6	2910	4153	0.71	31.1
Sept.	6.86	0.7	8.7	0.74	187	13	123	70	1.9	6923	36.4	3893	3453	1.13	27.9
Oct.	6.31	0.8	9.2	0.85	200	16	127	77	2.9	6526	37.5	3896	3598	1.08	31.4
Nov.	5.50	0.8	10.5	0.78	230	15	154	102	2.7	6934	41.6	4551	3398	1.34	34.2
Dec.	5.02	0.8	11.4	0.76	212	14	151	85	2.9	6196	41.7	3435	3171	1.08	34.9
1938															
Jan.	5.93	0.9	9.5	1.03	211	17	152	97	3.0	7393	37.9	3643	2983	1.22	31.0
Feb. 5	11.75	0.5	5.0	1.49	318	15	96	61	4.0	9012	22.7	5581	3140*	1.78	14.8
Feb. 6	9.41	0.7	6.0	1.55	124	12	75	66	4.0	5570	21.7	4865	3100	1.57	18.6
Feb 8	9.61	0.6	6.0	1.36	176	10	126	94	2.4	9898	27.5	7334	3180	2.31	18.4
Feb. 9	8.87	0.7	6.5	1.26	100	9	72	68	2.2	5170	22.5	4863	3700	1.31	23.2

* Aerators run in reverse. On Feb. 6 and 9, supernatant was added to the settled sewage.
N.B. Blower size use, 150 HP.

motor which is the motive power for a 3,000 cu. ft. per min. turbo-blower; eight 7½ HP. motors that rotate aerators of the paddle wheel type; also a 7½ HP. variable-speed motor for the return sludge. All of these motors are in service for 24 hours each day.

Based on the average daily flow, the amount of power consumed is as follows:

The settled sewage pumps use 62 kwh. per mg.
The return sludge pump uses 10 kwh. per m.g.
The aerator motors (8) use 127 kwh. per m.g.
The blower, 150 HP., uses 439 kwh. per m.g.

PUMPS

The settled sewage pumps are three in number and have a combined capacity of 18 m.g.d. or 6 m.g.d. each. They are controlled by a float

1. Two grit chambers with 20 m.g.d. capacity. Screen house contains two comminutors.
2. Three pre-settling tanks, 67 ft. by 31 ft. by 10 ft., with one-hour detention period.
3. Well house and garage.
4. Administration, laboratory and mechanical building; contains pumping and air equipment.
5. Four aerating tanks, 240 ft. by 109 ft. by 15 ft., with aeration period of 4½ hours.
6. Operating gallery; contains meters and control valves.
7. Four final settling tanks, 70 ft. diameter and 10 ft. deep, with two-hour detention period.
8. Four separate sludge digestors, 50 ft. diameter and 22 ft. deep; total capacity 1.3 million gallons; two floating and two fixed covers.
9. Four covered sludge drying beds, area 7,600 sq. ft. each.
10. The Grand River.
11. The State Prison of southern Michigan.

that varies their pumping capacity with the flow. This float operates a master control that varies the speed of the pumps from 470 r.p.m. to 570 r.p.m., and by various combination of pumps and speeds, the rate of pumping is from ½ m.g.d. to 18 m.g.d.

The two return sludge pumps are operated in a like manner, but at the present time only one pump is used to return activated sludge at the rate of 12 to 20 per cent of the flow. This pump will use from 60 to 65 kwh. per million gallon of return sludge.

Blowers

The blower equipment at Jackson consists of two 4,500 cu. ft., three-stage, single-flow, centrifugal blowers driven by 250 HP., 440 volt motors through speed increasing gears, and one 3,000 cu. ft. blower of the same type driven by a 150 HP. motor. The discharge pressure is 7.2 lb per sq. in., and it is possible to operate one, two, or three blowers at the same time. The amount of the air to be pumped is governed by a hand-controlled butterfly valve at the intake of each blower. By various combinations of blowers it is possible to vary the amount of air over a wide range.

The blower has a constant speed motor but the power it will consume varies with the amount of free air that it compresses. The figure of 439 kwh. per m.g. is based on using 0.8 cu. ft. of air per million gallons of sewage. When 0.6 cu. ft. is used, which is the lowest rate that has been tried, the blower will use 375 kwh. per m.g.; when 1.0 cu. ft. is required a larger blower is put into service, which has a 250 HP. motor and will consume 550 kwh. per m.g. of sewage. This blower comparison is based on the average daily flow of 6.4 million gallons. It is estimated that when the sewage flow increases to the plant's designed capacity, or 11.25 m.g.d., the kwh. for 0.6 cu. ft. per gallon is 311; for 0.8 cu. ft. two blowers or 400 HP. are put into service and 464 kwh. of power will be consumed; for 1.0 cu. ft. 554 kwh. will be required. The reason the power consumption is nearly the same for the present flow as estimated for the designed flow, is because of economies effected by the different combination of blowers that are required for the different amounts of air.

Aerators

There are four aeration tanks, each 240 ft. long, 12.75 ft. wide and 16.5 ft. deep with 1½ ft. freeboard (Fig. 2). The first half of the tank has a row of aeration plates on the bottom close to one side. The last half of the tank has paddle aerators on a central horizontal shaft. As the spiral flow of the sewage is started by the plates in the first half of the tank, the aerators can be revolved with the spiral or against it. There are also some plates in the last half of the tanks that blow air against the spiral flow but their area is only one-fourth of the plates in the first half of the tanks.

These tanks have been operated on the tapered aeration system; that is, the maximum amount of air has been put in at the influent end

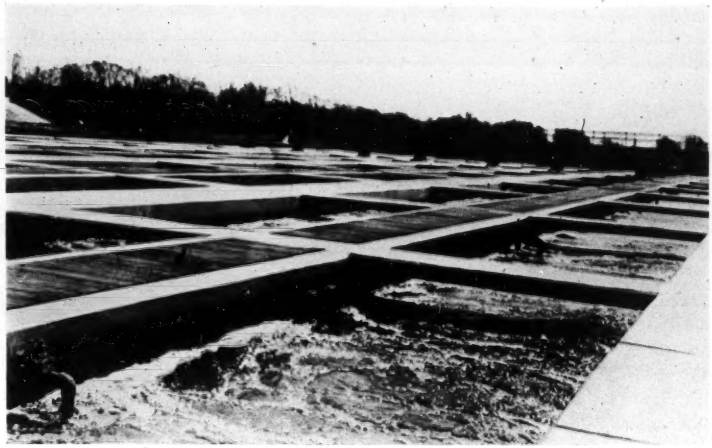


FIG. 2.—Aeration tanks in service.

and lesser amounts of air have been added toward the effluent end. The paddle aerators have been rotated with the spiral. It has been found that if the paddle aerators are used in this way the motors will use one-third of the power required when the paddles rotate against the spiral. The aerator motors will use about the same amount of power each day regardless of the flow through the tank as the paddle wheels are rotated at a constant speed of 3 r.p.m.

The power unit "Kilowatt-hours per day" used in this report (Table I) is an expression that places the power consumption of the basis of the sewage volume only and does not take into consideration the concentration or strength of the sewage. As the concentration of the sewage is highly variable and also changes considerably with the season, it is evident that a distorted conclusion can result from mere statement of the power figure. A proper power unit should be based on the energy required to do a given amount of work. In sewage treatment the best present method of measuring the work done is by means of suspended solids and biochemical oxygen demand determinations, which are the generally accepted efficiency tests of a treatment plant. If the number of pounds of suspended solids or pounds of B.O.D. *removed* during a given time is divided by the number of kilowatt-hours used in the same time, the resulting figure would represent the number of pounds removed per kilowatt-hour. It is believed that this unit is much better adapted for reporting operation data than is horse-power per million gallons or kilowatt-hours per million gallons because it is a definite expression of the amount of work done by a unit of energy. The Illinois Sanitary Water Board and some of the equipment manufacturers have adopted this method of measuring sewage plant efficiencies.

In Table I is shown the operation data for a period of six months and four days of storm flow. This table shows the suspended solids and the B.O.D. analysis, also the power consumed during this period. A comparison of HP. per m.g. and lb. per kwh. is to be found in columns 14 and 15, for the aeration tanks. The last three months of the table are of normal operation and show that one would expect 1.7 lb. of B.O.D. removal per kwh. at the present flow of 5.5 million gallons. But when the flow is doubled the removal of B.O.D. would be around 3 lb. per kwh. On the "work done" basis in the aeration tanks, the table shows that 1.2 lb. of B.O.D. removal per kwh. can be expected. If the flow is doubled the B.O.D. removal would be about 2 lb. per kwh.

As the table shows the unit "Lb. per kwh." has considerably more meaning and value than the units which are based on the sewage volume only. It is believed that by the adoption of this unit or one of similar meaning by engineers and chemists the power data would be much more comparable and valuable.

Conclusions

The power used for primary treatment of activated sludge plants where there is no pumping of sewage should be very low or about 8 to 10 per cent of the total power used.

The secondary treatment consumes about 90 to 92 per cent of the power; therefore, if any economy can be affected in the treatment of sewage by the activated sludge process, it must be in the secondary part of the plant.

In suggesting the unit of "Lb. per kwh." it is felt that a practical unit which is definite and can be safely compared is offered, and it is recommended that future power comparisons be based upon these units.

METHOD OF HANDLING SUPERNATANT LIQUOR

By R. A. Greene, *Ass't Sup't and Chemist*

The proper method of handling supernatant liquor has been debated by sewage works operators for some time. Some are inclined to believe that it should be drawn to sand beds and not given either primary or secondary treatment, others believe that it should be mixed with the primary effluent, while others believe, as we at the Jackson plant believe, that it should be mixed with the primary influent.

The digesters at the Jackson plant consist of two fixed covers and two floating covers, designed for two-stage digestion. We are following that procedure, using the fixed cover digesters for the first stage and the floating covers for the second stage. Both of the fixed cover tanks are kept full all of the time and all of the raw sludge is pumped into one or the other, forcing out either sludge or supernatant into the floating-cover digesters.

As a rule, we draw supernatant from the fixed cover to the floating cover digesters two days and sludge on the third day. This is by no

means a hard and fast rule, because the amount of sludge in the fixed covers really determines which we shall draw. We alternate the pumping of raw sludge into the fixed covers every day and, as the digesters are operated in pairs, the floating covers are alternated daily.

The regular procedure followed in handling supernatant has been to wait until the floating cover digesters are full, then draw it gradually. The operator takes a sample when he starts drawing and continues to take samples periodically as the cover goes down. The supernatant is drawn until it begins to get heavy, or until the cover comes almost to the stops. We know approximately the amount that can be drawn as we measure the sludge line each week. So far, we have drawn the supernatant by gravity, therefore the valve in the supernatant line has to be adjusted as the cover goes down to compensate for the loss in head.

During the past five months, that is, from October, 1937, through February, 1938, the gallons drawn and the rate, the suspended solids in p.p.m., and the per cent solids were as follows:

	Gallons	Time Hours	Gallons per Hour	Suspended Solids in P.p.m.	Per Cent Solids
October	309,000	114	2700	722	0.07
November	142,000	16	8880	590	0.06
December	373,530	62	6025	2377	0.24
January	377,430	49	7970	2870	0.29
February	555,000	61	9000	3075	0.30

The small amount drawn during the month of November was due to the fact that one of the digesters was emptied completely the latter part of October. The large amount drawn during February was due to the heavy rainfall, which made it necessary to pump a great deal more sludge.

The supernatant will not flow at a slow rate because of a rise in the line between the digesters and the primary tanks, which causes the line to become air locked unless the liquor is flowing at the rate of 6,000 or 8,000 gallons per hour. Therefore, from the above statement, the slow rate of 2,700 gallons per hour reported during October was not correct. At that time we were trying to draw at the rate of 4,000 or 5,000 gallons per hour, but part of the time no supernatant was leaving the digester. If, at any time in the future, we wish to draw at a slow rate, we will pump it against a partially closed valve.

As was stated at the outset, all supernatant from the floating cover digesters is drawn to the head of the primary tanks. Also, all supernatant drawn to the primary tanks comes from the floating covers. This has not seemed to upset our primary tanks in the least; by looking over the records, I find that the biochemical oxygen demand of the primary effluent is slightly higher when supernatant was drawn than with ordinary sewage, also the total nitrogen.

The supernatant has caused no ill effects in the secondary treatment

and very little difference can be noticed in the final effluent of the plant. To check this, the detention periods in the primary tanks and aeration tanks were calculated and a composited sample of the final effluent was taken while the supernatant was leaving the plant. This was analyzed together with the regular daily composite, and practically no difference was noted. As to stability, nitrites were, as a rule, a little higher when supernatant was present but this did not seem to affect the B.O.D. It would more likely affect the final effluent if the activated sludge were not in good condition or if the supernatant were drawn too fast when the aeration tanks were loaded. Certainly, good nitrification could not be expected under the latter conditions.

In conclusion, it may be said that the handling of supernatant here has been a small problem. In the light of the results obtained at the Jackson plant, it seems that in order to handle supernatant properly, it can be drawn to the entrance of the primary tank at as low a rate as is practical, and be given full treatment with the raw sewage.

The above conclusion is based upon approximately one year of operation during which time the plant has been operated at about one-half designed capacity with an excellent activated floc. However, we believe that the above method will also prove satisfactory when operating at the designed flow.

SOME EXPLANATION FOR THE LOW EFFLUENT B.O.D. AT JACKSON

By R. A. Greene, *Ass't Sup't and Chemist*

Ordinary drinking water generally runs higher in B.O.D. than the Jackson plant effluent; therefore, it appears to have more decomposable organic matter in it than our final effluent. The B.O.D. has been unusually low almost from the time the plant was placed into operation. A great deal of work has been contemplated on this subject. This is a progress report indicating the investigations that have been completed. All of these investigations point to the reported B.O.D. as being correct.

The Rideal-Stewart Modification of the Winkler method is used to determine the dissolved oxygen of all composited samples of the final effluent before and after the incubation period, and on all grab samples of the final effluent.

The procedure generally adopted in plants is to take the dissolved oxygen of the daily grab sample as the initial dissolved oxygen of the B.O.D. sample. This method was followed until September, 1937, when the B.O.D. began to look as though it would be on the negative side, and on several occasions since, had this method been used, the B.O.D. would have been negative. The average dissolved oxygen in the final effluent for the past nine months has been 7 p.p.m.; but on a few occasions it has been as low as 4 p.p.m. Very often there will be 6 or more p.p.m., dissolved oxygen after the sample has incubated five days.

Since the date above mentioned, dissolved oxygen has been determined on the composited sample and the result used as the initial dissolved oxygen of the sample. The composited sample usually contains from 8.0 to 9.5 p.p.m. dissolved oxygen.

The B.O.D. samples are taken from the daily composited sample, which is collected hourly in proportion to the rate of flow. These daily samples are kept in a refrigerator at 4 deg. C., and on each week day, at the end of the 24-hour compositing period, B.O.D. samples are plated and incubated at 20 deg. C. for five days. The B.O.D. on the final effluent is run practically all the time without any dilution.

The B.O.D. of the final effluent has averaged 2.9 p.p.m. for the last five months (October 1, 1937 to March 1, 1938). At first it was thought that we might be obtaining oxygen from the nitrates, which run high in the final effluent, but when duplicate samples were run for several days, there was not a single instance found where the nitrite and nitrate value had changed. If these samples are getting oxygen from any other source we do not know where, and it does not seem reasonable that they would require oxygen from any other source than the dilution water, as there is always at least 2 p.p.m. dissolved oxygen after the incubation period, and most of the time 4 p.p.m. or more. Samples have been plated with different dilutions and they give the same B.O.D. as the undiluted samples.

The final effluent is very stable based on the results of weekly analyses. The following table gives the average weekly results of analysis of the raw sewage and the final effluent.

Raw Sewage

	Suspended Solids, P.p.m.	D.O., P.p.m.	Org.-N, P.p.m.	NH_3-N, P.p.m.	Oxygen Consumed, P.p.m.	B.O.D., P.p.m.
October	200	0.2	9.3	15.6	57.4	126
November	230	0.4	10.4	16.3	62.4	154
December	212	1.2	10.4	15.0	56.5	151
January	211	2.0	9.7	15.7	57.5	152
February	157	2.8	6.9	10.8	51.4	104

Final Effluent

	Suspended Solids, P.p.m.	Per Ct. Red.	D.O., P.p.m.	Org.-N, P.p.m.	NH_3-N, P.p.m.	Oxygen Consumed P.p.m.	B.O.D., P.p.m.	Per Ct. Red.	NO_2-N, P.p.m.	NO_3-N, P.p.m.
October	16	92.0	6.0	2.9	1.7	8.1	2.9	97.5	0.4	13.3
November	15	93.5	7.0	3.1	1.3	8.4	2.7	98.0	0.2	14.6
December	14	93.5	8.0	2.5	1.6	7.2	2.9	98.0	0.3	14.1
January	16.6	92.5	7.0	4.0	4.9	7.3	3.0	98.0	0.6	12.2
February	15	90.5	6.6	3.9	5.0	8.9	2.8	97.0	1.6	7.0

The reduction in organic nitrogen, oxygen consumed, and the nitrification, within the above limits, have not affected the B.O.D. of the final effluent. The amount of suspended solids in the final effluent has remained about the same over the five-month period. During the months of October, November, December, and January, we were treating between 5.5 and 6 million gallons daily, but during February the flow averaged almost nine m.g.d., and a great deal of the time we were treating all that the plant was designed for, which is 11.25 m.g.d. Jackson has a combined system of sewers with very few separate storm sewers, consequently this high flow was due to rain and melting snow and probably part of Grand River, which was at a high stage practically all the month. Therefore, during this month the sewage was diluted and one would naturally not expect as high a degree of treatment, as measured by per cent of removals and nitrification, to obtain an effluent of the same stability. The averages for the month of January are the ones which look confusing, as the flow into the plant was about the same as in October, November, and December, and the sewage was about the same strength but the percentage reduction was lower. The only explanation which can be given for this is the mechanical difficulties encountered with the paddle agitators in the aeration tanks. The gears were worn so that some had to be taken out of service and the remaining paddles were rotated with the air instead of against it; this change in mode of operation is clearly indicated by the various analyses of the final effluent; the oxygen consumed test has remained rather constant along with the B.O.D.

In order to obtain a low B.O.D. it does not seem necessary to have a high degree of nitrification, but in our case we were getting it because we could not conveniently avoid it. With the flow between 5.5 and 6 m.g.d., a definite amount of air must be used to keep the mixed liquor from settling before it gets through the paddle wheel section, and the detention period is so lengthened with this flow that we get the high nitrification. The mixed liquor has about 3,000 p.p.m. suspended solids and the sludge index is approximately 30.

In conclusion, it can be said that we are assured that the effluent from the plant is exceptionally good, both from the results of analysis and from the physical appearance as it mixes with Grand River. We also know that the effluent will sustain fish life as we have had about fifty goldfish in each of the four final clarifiers for about six months. Likewise, fish are constantly seen around the effluent channel from the plant.

We question if the five-day B.O.D. in our plant truly represents 67 per cent of the total B.O.D.

EXPERIENCES AND RESULTS OF FIRST YEAR OF OPERATION OF THE ANN ARBOR SEWAGE TREATMENT PLANT *

By Harland P. Dodge

Superintendent

The Ann Arbor Sewage Treatment Plant (Fig.1) is located on a 50-acre tract of land on the north bank of the Huron River three miles east of the eastern city limits. The site is bounded by the river on

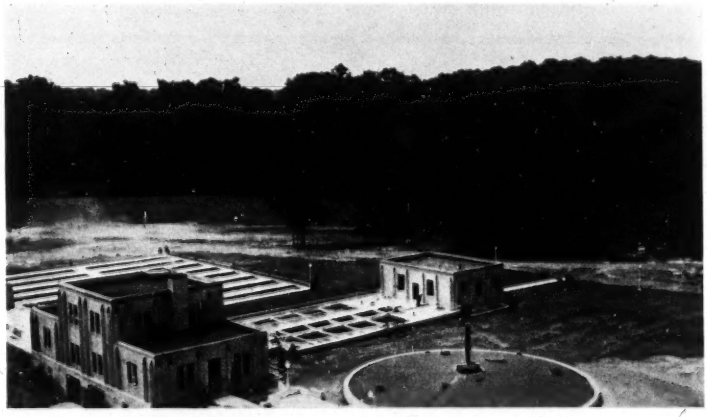


Fig. 1.—View of Ann Arbor Plant.

three sides and by the Michigan Central Railroad on the fourth side, providing a well isolated area which is to be developed for park purposes. The plant effluent is discharged into the upstream end of a power pond. There are five such ponds in the thirty-five miles between the plant site and the northwest corner of Lake Erie, into which the river discharges.

The design capacity of the plant is 4.5 m.g.d. The average sewage flow for the first year was 3.7 m.g.d. based on meter records which were available at different periods aggregating about one-half of the year.

The sewerage system is of the separate type, however, heavy rains have increased daily flows as much as 1.5 million gallons.

About 12 per cent of the total flow of city sewage is tributary to the old main sewer. This portion of the flow is pumped to the new main trunk sewer, through which it is conducted by gravity to the plant.

* Presented at the Thirteenth Annual Conference of the Michigan Sewage Works Association, East Lansing, March 30–April 1, 1938.

General Features

The plant is of the activated-sludge type with separate sludge digestion (Fig. 2). The sewage first passes through a 25-in. Comminutor

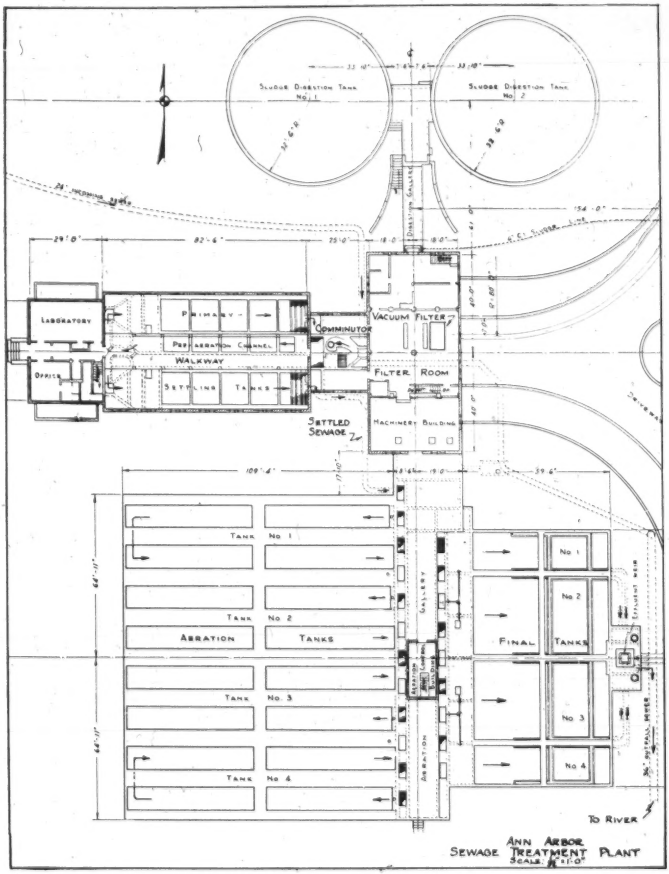


Fig. 2.—Plan of Ann Arbor Plant.

and a pre-aeration channel which provides a 12 min. aeration period for the design flow. Pre-aeration is employed to coagulate oil and grease, which is skimmed from the primary tanks and burned in a gas-fired incinerator.

There are two primary settling tanks 78 by 16 ft. in plan with a 10 ft. 6 in. average water depth. Straight-line sludge collecting mechanisms are employed in both the primary and final settling tanks.

Each of the four aeration tanks includes two channels 108 by 15 ft. in plan, with a water depth of 15 ft., so arranged that each pair may be operated in series. The tanks are the spiral-flow type with two rows of diffuser plates. The aeration period is 6 hours on the basis of 4.5 m.g.d. with 25 per cent return sludge.

There are four final settling tanks, two of which are 65 by 16 ft. in plan with an average water depth of 11 feet (Fig. 3). The other two

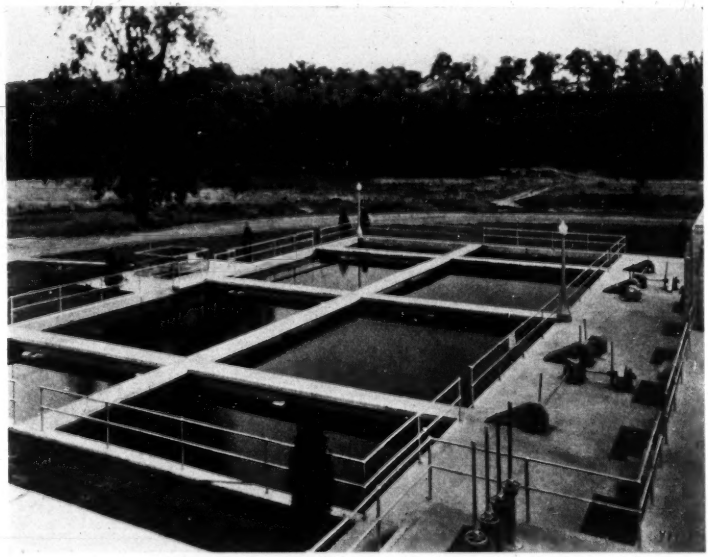


FIG. 3.—Final settling tanks.

tanks, 65 by 33 by 11 ft., have two sets of sludge-collecting mechanisms and a cross collector at the hopper end. Each tank has two cross weirs and two side weirs of length equivalent to the periphery of a circular tank of equivalent capacity. The side weirs start 27 ft. from the inlet end of the tanks and the first cross weir is 41 ft. from the entrance.

The two sludge digestion tanks, equipped with floating covers, are 65 ft. in diameter and 29 ft. deep at the center, with side-wall depths of 19 ft. The sides of the covers project 5 ft. below the ceiling plate so that they may act as gasometers, each with a storage capacity of 15,000 cu. ft. The tanks, arranged to operate in parallel or series, each have a volume of 72,000 cu. ft., or 3 cu. ft. per capita for the design population. The primary tank is equipped with a 500 gal. per min. supernatant circulating pump suspended from the lower side of the cover. The supernatant is discharged from four nozzles projecting through the cover and spaced evenly 25 ft. from the center of the tank, and from one

outlet located under the gas dome. The purpose of supernatant circulation is to break up any heavy dry scum which may accumulate during the time when the cover is storing gas, consequently not keeping the scum submerged. Each tank is heated by water circulated through three coils of 2½ in. wrought iron pipe, supported on concrete posts 7 ft. from the walls and located vertically in about the middle third of the tank. Supernatant liquor can be withdrawn from the center of the tanks at four 3 ft. intervals.

Sludge is conditioned with lime and ferric chloride and dewatered on a vacuum filter 6 ft. in diameter and 10 ft. long.

The compact arrangement and general accessibility of the units of the plant, all of which are connected by galleries, is worthy of particular mention. Another feature of interest is the meter panels, which are located in the corridor of the office building. These panels contain sixteen 24 hr. dial charts on which the rates of flow are recorded. There are also indicating dials which are located adjacent to the meters.

Discussion of Results of Sedimentation

The results obtained during the first year of operation of the plant are indicated briefly in the accompanying tables. The suspended solids in the raw sewage averaged 278 p.p.m. and the 5-day B.O.D. 304 p.p.m. This amounts to 0.22 lbs. and 0.25 lbs. per capita per day of suspended solids and 5-day B.O.D. respectively.

Table I.—*Ann Arbor Plant*
Flow, Suspended Solids and B.O.D.

Month 1937	Flow, M.g.d.	Suspended Solids P.p.m.						5-day B.O.D. P.p.m.					D.O. P.p.m.
		Raw Sewage	Settled Sewage	Plant Effluent	Per Cent Volatile	Per Cent Reduction		Raw Sewage	Settled Sewage	Plant Effluent	Per Cent Reduction		Effluent
						Settled	Effluent				Settled	Effluent	
Jan.	*												
Feb.	3.5	229	129	72		43	68†						
Mar.	3.3	235	134	76		43	68						
Apr.	4.1	223	134	75		41	68						
May	4.2	230	124	53	73	45	78	281	164	48	45	83	
June	4.0	291	179	22	71	38	91	358	216	23	40	94	
July	3.6	346	169	18	72	51	95	395	213	22	46	94	4.3
Aug.	3.8	336	182	26	72	45	91	332	192	15	42	96	3.2
Sept.	3.5	297	146	20	71	51	93	266	156	10	41	96	3.5
Oct.	3.5	298	140	27	72	53	91	275	147	21	47	92	4.3
Nov.	3.5	304	147	49	71	38	86‡	248	154	35	38	86	3.6
Dec.	3.7	270	156	46	72	42	83	276	161	37	42	87	4.8
Avg.	3.7	278	150	44	72	46	84	304	175	26	42	91	4.0

* No analyses were made during January.
† Settling in both primary and final tanks without aeration to May 1st.
‡ Bulking of activated sludge during November and December.

TABLE II.—*Ann Arbor Plant*
Nitrogen Data

Month 1937	Nitrogen as N—P.p.m.							
	NH_3			NO_2	NO_3	Organic N		
	Influent	Settled	Effluent	Effluent	Effluent	Influent	Settled	Effluent
July	20	20	12	0.2	1.6	20	13	6
Aug.	16	16	13	0.1	0.2	22	20	6
Sept.	17	17	11	1.9	0.2	18	12	6
Oct.	17	17	12	2.1	0.4	23	16	10
Nov.	19	19	6	2.6	6.4	21	14	10
Dec.	18	18	6	1.6	7.8	18	12	8
Avg.	18	18	8	1.4	2.8	20	15	7

TABLE III.—*Ann Arbor Plant*
Detention Periods and Return Sludge

Month 1937	Detention Periods			Per Cent Return Sludge
	Primary Tanks	Aeration Tanks	Final Tanks	
Jan.				
Feb.	1 hr. 17 min.		3 hr. 39 min.	
March	1 hr. 22 min.		3 hr. 52 min.	
April	1 hr. 06 min.		3 hr. 07 min.	
May	1 hr. 04 min.	*9 hr. 30 min.	3 hr. 30 min.	30+
June	1 hr. 07 min.	6 hr. 41 min.	2 hr. 31 min.	27†
July	1 hr. 15 min.	7 hr. 27 min.	2 hr. 48 min.	27†
Aug.	1 hr. 11 min.	7 hr. 04 min.	2 hr. 39 min.	27†
Sept.	1 hr. 17 min.	7 hr. 39 min.	2 hr. 52 min.	27†
Oct.	1 hr. 17 min.	7 hr. 39 min.	2 hr. 52 min.	27†
Nov.	1 hr. 17 min.	7 hr. 39 min.	2 hr. 52 min.	27†
Dec.	1 hr. 13 min.	7 hr. 14 min.	2 hr. 43 min.	27†

* The activated sludge was developed during the month of May.
† Due to its sensitive nature the percentage of return sludge was maintained rather high. Air requirements have been 1 cu. ft. per gallon of sewage.

From January 1 through April the sewage passed through both the primary and final settling tanks without aeration. During this period a 43 per cent reduction in suspended solids was effected in the primary settling tanks. The primary tanks are designed for a settling period of one hour for 4.5 m.g.d. The settling period during this time was one hour and 15 minutes, or 1,500 gallons per sq. ft. of tank area per 24 hours.

The raw sludge which was pumped to the digesters averaged 4.9 per cent solids. The sludge collecting mechanism was operated continuously for a period of one month to note the effect on the solids concentration. No measurable difference was noted in favor of either continuous or part-time operation of the mechanism.

The final settling tanks are designed for a 2.25 hr. settling period for 4.5 m.g.d. plus 25 per cent return sludge. During the four-month period in which double settling was employed, 68 per cent of the suspended solids were removed. The settling period in the final tanks was 3.5 hours, or 565 gal. per sq. ft. of tank area per 24 hours. Sludge from the secondary tanks averaged 3.5 per cent solids.

During the 4½ months after the activated sludge process was developed, removals of 92 and 94 per cent of suspended solids and 5-day B.O.D., respectively, were effected.

Aeration

Air is supplied by two motor-driven positive pressure type blowers of 1,500 and 2,000 cu. ft. per min. capacity and one gas-engine driven blower of 3,000 c.f.m. capacity. The motor-driven units, operated by 60 and 100 H.P. induction motors equipped with two sets of windings, may be operated at half capacity. This arrangement and the speed variations possible in the gas-engine driven unit provide considerable flexibility in the volume of air which may be delivered.

The aeration process was started May 1, 1937. A typical activated sludge was developed in about four weeks. At that time 3,600 p.p.m. of suspended solids were carried in the mixed liquor but the air requirements were higher than desired, so the solids were gradually reduced to 1,600 p.p.m. The results obtained with this concentration of solids were satisfactory and the air consumption was about 1.0 cu. ft. per gallon of sewage. The amount of return sludge was maintained practically constant averaging 27 per cent of the incoming sewage, with 0.5 per cent solids.

The activated sludge was rather sensitive to changes in the amount of dissolved oxygen carried in the aeration tanks, and occasional temporary upsets were experienced due to excessive amounts of supernatant liquor being returned to the incoming sewage.

On October 13, the first real case of bulking occurred. A microscopical examination of the activated sludge showed an excessive growth of the filamentous organism which had been present to some extent since the sludge was first developed. The aeration and final tanks were drained and flushed and the development of a new activated sludge was started.

On October 31st a heavy discharge of copper waste from an unknown source increased the suspended solids from the normal Sunday average of 225 p.p.m. to 625 p.p.m. This same type of waste continued to arrive for the next four days with the result that the aeration process was again seriously retarded.

During the rebuilding process the filamentous growth, which was identified as *Sphaerotilus*, became excessive but soon started to gather into comparatively thick mats resembling light gray tissue paper. With the disappearance of these mats the sludge improved rapidly and fairly good results were produced.

The sludge index of 82, obtained during the month of December, was the lowest monthly average, but the removal of suspended solids effected was 12 per cent below that of July when the average index was 164. However, the effluent contained an average of 46 p.p.m. of very finely divided floc. In an attempt to remove this light floc the solids concentration in the mixed liquor was gradually increased to 2,800 p.p.m. at which point the index suddenly increased into the 300 range and the sludge did not readily respond to treatment which is normally successful in reactivation. Lime and clay were applied but proved beneficial for only one day after application. It was necessary to develop a new activated sludge before satisfactory results could be obtained.

To date the most satisfactory means of wasting excess activated sludge has been to return it to the primary settling tanks during the early morning when the settling period is about 2 hours.

Digestion

The sludge digestion tanks were put into service December 29, 1936, without the aid of heat and results were about normal for tanks which are started in the winter under such conditions.

Sewage was first pumped into the digesters to lift the floating covers. The process of filling was rather slow while using two 50 g.p.m. sludge pumps so the idea was conceived that, by the proper manipulation of valves, which were intended for other purposes, a 1,000 g.p.m. drainage pump taking its suction from the final tanks could be used for this purpose. Soon after this pump was started, it was noted on looking out of a window over a one-story section of the building that the roof of the building was covered with secondary sludge about 15 inches deep and well above the roof flashing. Investigation soon disclosed that the roof drain from that section of the building was connected to the normal discharge line of the drainage pump. Unfortunately the down-spout was on the wrong side of one of the valves which made the use of this pump possible so that the discharge was divided between the roof and the digestion tank. Sludge leaked through joints of brick and tile to the blower room below so a washing down was immediately in order and one of our embryo plant operators gave up his lunch and all aspirations of becoming an operator and returned to his former occupation. An equipment company representative who was adjusting equipment on the second floor had noticed the sludge on the roof but did not report it because he had assumed the process to be a normal operating routine.

On March 15, it was discovered that the small amount of gas being formed could not escape through the intended outlet. The gas lines at the middle of the digestion tanks were found to be plugged with sheet-metal flanges which had been placed there for testing the lines against leakage while under pressure. Apparently they served their purpose well for no gas was able to reach the boilers and other gas appurten-

ances. To remove these obstructions it was necessary to transfer sludge from one tank to the other and to dismantle a small amount of pipe.

When heating was started on March 30, by using the auxiliary coal-fired boiler which was no longer required for full-time heating of the buildings, a loss of water from the heating coils indicated that trouble of a different nature existed within the tanks. An air blow-off line from a high point in the heating coils, extending through the wall into the digestion gallery, had been sheared by the weight of heavy scum when the cover was lowered. Removal of a portion of the sludge from each tank was again necessary to permit minor repairs.

On July 31, the first gas that could be burned in the boilers was produced at about the same time that the digesters were full, with no digested sludge in sight. The volatile content of the sludge in both tanks was about 70 per cent.

It was then decided to dewater raw sludge but numerous unforeseen difficulties prevented much progress along this line. It was soon found that no compressed air could reach the filter compartments to assist in removing the filter cake. Paper placed in the filter head valve openings at the manufacturing plant, to prevent the entrance of dirt, had not been removed when the equipment was assembled. The filtrate pump would run but a short time when, due to excess heat, it would be automatically stopped. This difficulty was found to be due to the fact that all the motor leads had been erroneously marked at the factory and electrical connections had been made accordingly. The proper changes were made and when put in service the pump would occasionally fail to discharge the filtrate at the proper rate. The motor was then found to be rotating in the wrong direction but in spite of this fact it was doing a fairly acceptable job. Considerable annoyance was also caused by lime solution leaking from the slaking tank around the agitator shaft. This was also found due to a motor running backwards. These difficulties along with many others retarded sludge dewatering to such an extent that the long anticipated case of foaming was in progress before any headway was made in reducing the load in the digesters.

When the sludge flowed down the stairway, leading to the top of the digesters, and into an areaway, thence through the windows into the pump room, the easiest way to get rid of it appeared to be by flushing it down the areaway drains, so the drain castings were removed and more sludge was pushed into the areaway and plenty of water provided to flush it to a drainage sump. This procedure was followed for some time until it was discovered that the drainage line under the building had become plugged and the greater portion of the sludge had backed up into a pipe gallery between the primary settling tanks. At that time we received our only complaint of odors from our nearest neighbor, about 2,000 feet from the plant, and an unusual amount of bad supernatant liquor upset the aeration process for about two weeks.

Digestion and gas production are now (March, 1938) proceeding satisfactorily, with a gas production of about 50,000 cu. ft. per day

from a tributary population of 39,000. Fifteen cu. ft. of gas have been produced per lb. of volatile matter destroyed. The heating value of the gas, since November 15, has averaged about 650 B.T.U. per cu. ft.

The volatile matter in the raw sludge has averaged 78.5 per cent and in digested sludge 57.5 per cent, giving a reduction in volatile matter of 63.1 per cent.

Incineration of scum and grease was practiced before the gas engine was placed in operation. Except when received in abnormal amounts, scum and grease are now pumped to the digesters in order that the gas supply might be conserved for use in the engine. There is less than 2 ft. of scum on the primary digester at the present time.

Sludge Drying

Sludge drying has been the minimum necessary to permit use of the digestion tanks.

Data concerning filter operation and amounts of chemicals required are not available due to difficulties in metering sludge caused by entrained gas. An automatic gas relief valve is to be installed on the digested sludge venturi meter to eliminate trouble from this source.

Best filtering results have been obtained by placing the heavy canton flannel filter cloth on the filter drum with the smooth surface to the outside. A lighter weight material is to be tried when the supply of cloth furnished with the filter is exhausted.

To date all of the dried sludge has been utilized on the plant grounds. Inquiries concerning sludge have been received from a nearby estate and from farmers, so it is not expected that sludge disposal will be an immediate problem.

Utilization of Gas

Gas is used for heating the buildings, for laboratory purposes and as fuel for an incinerator in which screenings are burned. The main use of the gas, however, is as fuel for a 120 H.P. four cylinder, Worthington gas engine which is directly connected to a 3,000 c.f.m. positive pressure type of blower. Gas with a heating value of about 450 B.T.U. per cu. ft. was said to be a minimum requirement for satisfactory operation of the engine. When gas of this quality was produced during the first week of November many unsuccessful attempts were made to put the engine into service. The difficulties encountered were in the magneto but were overcome by wiring changes after correct instructions were received from the manufacturer. The engine was put into service the first of December. Oil consumption was rather excessive for the first two weeks but this was overcome partially by a change of oil and by replacing the oil wiper rings with improved types.

The engine is now operating satisfactorily about 20 hours per day. Fuel consumption has been 1,800 cu. ft. per hour or 15 cu. ft. per rated B.H.P. hour. On the basis of the average fuel value of the gas produced this amounts to 9,750 B.T.U. per B.H.P. hour.

The cooling water for the gas engine is utilized for heating the diges-

tion tanks and has been found to be more than ample. During the time when sufficient gas was available to run the engine 24 hours per day the temperature of the digestion tanks reached 107° F. The temperature of the cooling water as it left the engine jacket was 165° F. Heat dissipation to the digestion tank contents through 2½ in. wrought-iron pipe coils was found to be 16.5 B.T.U. per sq. ft. per hour per degree difference of temperature. This is about one-half of the heat loss which was indicated in the only reference found on the subject.

In order to insure any desired digestion temperature and continuous use of the gas engine, without overheating, additional cooling coils of 2½ in. wrought iron pipe were installed in one of the aeration tanks. A meter and thermometers were installed in the lines so that heat losses from this source could be determined. With the temperature of the aeration tank contents at 55° F. the heat loss was 103 B.T.U. per sq. ft. per hour per degree difference of temperature, or about six times the amount dissipated in the digestion tanks.

Cost

The plant, which was designed jointly by Ayres, Lewis, Norris and May, and Shoecraft, Drury and McNamee, two local consulting engineering firms, was built as a P.W.A. project at a cost of $457,400 of which $124,000 was a Federal grant.

Prior to the construction of the sewage treatment plant, a new main trunk sanitary sewer, about five miles long, was built through the city and was later extended four miles down the river to the plant site, as a C.W.A. project. The costs of the main sewers and the treatment plant were as follows:

Main Trunk Sanitary Sewer	$ 324,864.43
Down River Sewer	279,666.09
Land	9,300.00
Sewage Treatment Plant, Pumping Station and Bridge	457,378.03
Total Cost	$1,071,208.55

Federal Grants

Down River Sewer	$200,654.60	
Sewage Treatment Plant	124,000.00	
University of Mich. Main Trunk Sanitary Sewer	10,987.00	$335,641.60
Net Cost to City		$735,566.95

The total operating expense, including billing and collecting, depreciation and debt service, for the past year was $41,800. The estimated annual cost in the future is $65,000 based on operation of the aeration process throughout the year. Ample operating revenue is obtained by a utility service charge collected by the water department and based on the amount of water consumed during the winter months. The total revenue amounts to approximately 50 per cent of that collected for annual water service.

Comments

The first year of operation of the Ann Arbor Sewage Treatment Plant, just described, which ended January 1, 1938, was rather typical of first years in that a considerable amount of time was spent in making the usual adjustments which are necessary when the amount of new equipment which is found in the modern plant is placed in operation. Many experiences have not been mentioned, some of which were merely amusing but in general they were educational in that as a result of them the operators learned at an early date the function, mechanics, and care of the equipment.

The past year may well be divided into three operating periods as follows:

January through March —The period during which double settling was employed.

April through October —The period during which the activated sludge process was established and functioned efficiently.

November and December—The period during which bulking of the activated sludge occurred.

Examination of the operating data will disclose that the results obtained during the entire year have been satisfactory in spite of the difficulties encountered.

Industrial Wastes

TEXTILE WASTE DISPOSAL AN ORDERLY APPROACH TO THE PROBLEM *

By L. L. Hedgepeth and C. B. Griffin, Jr.

Technical Service Department, Pennsylvania Salt Mfg. Co., Philadelphia, Pa.

We have agreed that, if we were to select a text for the theme of our presentation to you of the problem of waste disposal, it would be the sage observation on this problem by Geyer and Perry in their excellent report to the Textile Foundation:

> The textile waste treatment problem is more complex than many other industrial waste purification problems because of the fact that no two textile wastes are alike in character, nor can any two wastes be purified by exactly the same treatment. The combined waste from each mill is different, and the waste from any one mill continually changes with the introduction of new processes or the change in market demands. Textile wastes are as varied in character as the kinds and colors of the goods produced within the mills. . . . Each problem must be studied carefully in order that its solution may conform to sound economic principles of conservation.

The subject of textile waste disposal is one of importance to this group. It is not the intent of this paper to call your attention to this problem for that already has been done, more forcibly in some states than in others. Some of these laws have teeth in them, too—even mentioning that "cease and desist" notices will be sent to those industrial plants whose effluent does not meet certain rigid specifications on specific dates. However, when we consider the fact that the textile industry is one of the contributors, if not the greatest contributor of industrial waste liquors to streams in this section, we do not have much room to grumble. After all, no one, not even a textile man, would like to catch fish of a beautiful hue composed of sulfur black, Blue 4R powder, and Conc. Green RB. We'd probably say that the shade was off or that there were hard water "resists" or that colors clashed or perhaps say that the designer just had a bad day. Nor would a textile man like to sit under a shady tree by a small stream and observe wool-scouring wastes flowing by or smell their rare odors.

All laws considered, the textile industry is perhaps more fortunate than some others, for instance chemical manufacturers, who in many cases have to contend not only with stream pollution but with atmospheric pollution as well.

It is well at this time that a careful approach to the problem be discussed. The disposal of waste liquors in a textile mill is usually a disagreeable topic for three distinct reasons:

* Presented at the Philadelphia Section Meeting of the American Association of Textile Chemists and Colorists, March 4, 1938.

1. No two textile wastes are alike in character, nor can any two wastes be handled in exactly the same manner. The combined wastes from a mill change in character almost hourly and the waste from one department changes continually with changes in processing methods and new developments. In fact, the most consistent thing about textile wastes is the fact that they will consistently change.

2. The physical treatment and handling of textile waste liquors is far more difficult than the treatment of ordinary municipal sewage. Generally, it is more difficult to dispose of the sludge and very often hard and obnoxious problems come up. A good example of an obnoxious problem is as follows:

   We know of a plant which formerly used a compound containing about 20 per cent cresylic acid in its yarn-scouring operations. The yarn-scouring waste liquors composed only a small percentage of its total volume of waste liquors, all of which were emptied into a fairly large river, yet a municipal water plant 25 miles downstream complained of bad tastes and odors due to chlorinated phenols when chlorine reacted with cresylic acid. The complaint was settled by changing the mill's yarn-scouring formula to eliminate cresylic acid. Nothing else was needed in the way of pollution abatement.

3. Very few mills, either old established concerns or modern mills, have ever made up, as a separate justifiable budget item, an account for taking care of waste liquors. A large number of mill owners have for years looked upon any money or effort spent for disposal of waste liquors as an added overhead burden or investment from which no tangible return could ever be expected. This latter reason is probably the most disagreeable of the three mentioned and rightly so.

However, disagreeable or not, the problem still remains and it is one that cannot be handled in a hit-or-miss fashion. Many of you will be approached by persons with a story similar to this: "We have here a process. Build your disposal plant in accordance with these exact plans. Add so many grains of alum, or copperas, or phosphates, or activated carbon, or what have you, per gallon. Then add so many parts per million chlorine. Mix, coagulate, settle, recirculate sludge, empty the effluent into the stream, and pay us a small royalty. It will be perfectly safe, etc." The problem, gentlemen, is not so simple as that. This whole situation might be a relative Utopia if such were true. It is true that liquors from certain mills will be handled more easily than those from others and that in some few cases recognized sewage treatment methods may be applied, but for the most part the problem at each plant is individual, which will require time and effort before the best and most economical treatment is established. If patent-medicine treatments are applied, the owner will wake up one

fine day with an ache in the head and an even bigger ache in the pocketbook. He'll have a fine looking disposal plant on his hands which does nothing. The key to the situation is this: The textile man must not look upon the waste disposal problem from the viewpoint of a textile man, but he must completely re-orient himself to the viewpoint of a sewage man. We do not mean that the textile technician's experience, common sense, and sound business reasoning are to be discounted, but that waste treatment cannot be viewed in the same light as a proposed change in a bleaching or scouring procedure, or a change in weaving methods, or cloth construction. *The textile man to a degree must become a sewage man* whether he likes it or not. He must become accustomed to thinking in such terms as parts per million, B.O.D. (biochemical oxygen demand), grains per gallon, suspended solids, and forget completely such measurements as degrees Twaddell, and such terms as "sour," "handle," "chemic," and percentage by weight formulae. He must also forget about Special Oil KW–60, which is doing fine work in his dye bath, and Softener No. 22, which is working wonders on his Style No. 866 goods, and consider the lowly heavy chemicals, such as copperas, alum, lime, and phosphates, which not only fail to bear mysterious letters and lordly labels, but which generally may be purchased by the ton for less than the cost of 100 lb. of the average textile specialty. In other words, waste treatment requires that we come down to basic scientific facts and ways of thinking and that we avoid all rule-of-thumb methods and patent medicine or specialty cures.

The problem, therefore, becomes one which not only requires physical and chemical alterations, but one that makes mental readjustment almost a necessity.

We may outline an approach as follows:

1. Assume the mental attitude of a sewage treatment man who weighs his problem carefully against stream flow, upriver pollution, downriver use of stream, the added hazard of dangerous proximity to public water supply intakes, and other factors which added together determine the capacity of the stream to absorb the shock without creation of nuisance.

2. Study carefully the regulations of the stream pollution authority having jurisdiction and determine the degree of treatment to which the effluent of the plant must conform before it is released.

3. Consider thoroughly any changes in the present methods of plant operation which may ease the disposal problem. To emphasize the above, we need ask only a few pertinent questions.

a. Can old dyeing machines be replaced with new type machines which require smaller volumes of dye liquor?

b. Will the application of counter-flow washing principles reduce the waste liquor volume sufficiently to make the installation an economical one?

c. Can certain dyestuffs, which aggravate the disposal problem, be avoided in favor of others which may be more easily handled?

d. Are the effluents from the last one or two washers, of a group connected in series, sufficiently clean for re-use, or if they cannot be re-used economically, are they sufficiently pure to be run directly into a stream rather than increasing the volume of liquor to be treated?

e. Can the frosted wool or the solvent method of wool-scouring be substituted for the soap-soda ash method?

f. Will it be economical to recover caustic soda by dialysis or centrifuging and evaporation?

In other words, can the discharge of valuable chemicals into the stream be partly avoided by modernizing equipment and methods?

4. Determine carefully whether the waste liquors can be handled directly by the municipal sewage plant. Determine also whether the waste may be subjected to a mild treatment at the plant and then run into the municipal sewers. This method is generally the most satisfactory method of handling waste liquors, but it necessitates complete cooperation between mill and sewage plant. It may be necessary for the mill to construct holding tanks for its liquors and to release definite volumes, at times agreed upon by the sewage plant management, and which have been partially treated to the degree requested.

5. If a disposal plant must be constructed for the mill, have the technical staff consult with competent authorities and set up a pilot plant for complete trials in order that the physical and chemical treatment of the waste may be worked out in the most economical and satisfactory manner. It is important that this be done before preparation of plans for the final plant, unless there is good reason to believe that previous experience with similar wastes justify basing plant design on experience gathered elsewhere, rather than in your own plant. Otherwise, much money and nervous energy will be dissipated with small return.

6. It is important when large scale operation begins that the disposal plant have competent management or it will become a problem child. The fact that a second hand or foreman knows the "art of finishing" or the "art of sizing" does not by any means indicate that he can properly supervise a waste disposal plant. We cannot stress too much the necessity of controlled operation for satisfactory results. Waste disposal under poor supervision can become another fly in the ointment, such as the recession, C.I.O., or unfavorable trade treaties; but under careful, conscientious management, it can become another smooth-working department of which a mill may well be proud.

We once read in a British textile journal a statement somewhat to the effect that "more hearts and pocket-books have broken over textile waste problems than any other one activity in the British textile industry," and with this as a leading thought we conclude these remarks with the suggestion that each plant's problem be considered separately for waste disposal problems and to beware of the specialty product—

its miracle helpeth you not. Sewage is real—it stinketh—it leaveth nothing to the imagination. Beware also of the proprietary or patented process for, like the mule, it is without pride of ancestry or hope of posterity.

The processes of sewage treatment are well established and understood—their good points proved—their limitations admitted; and, in the words of Potter "The search for a chemical that will completely deodorize, stabilize, and purify sewage belongs in the same category as the search for the Fountain of Youth."

Stream Pollution

SOME FACTORS AFFECTING THE AEROBIC DECOMPOSITION OF SEWAGE SLUDGE DEPOSITS *

By H. G. Baity

Professor of Sanitary Engineering, Division of Public Health, University of North Carolina, Chapel Hill, N. C.

The suspended matter in discharged raw sewage has a very important influence on the physical appearance and the chemical quality of the water of the receiving stream. Some of the suspended solids float to the surface, but the settleable matter precipitates and forms sludge banks on the beds of waterways, the amount, character and location of which depend upon the nature of the sewage and the conditions of stream or tidal flow. Instances have been cited where such deposits attained depths of several feet and extended for many miles along sluggish streams. Sludge banks of this organic character undergo continuous decomposition through the agency of bacteria and other forms of aquatic life, thereby robbing the overlying water of its dissolved oxygen. In spite of an apparently sufficient dilution of stream water to care for wastes being received, the constant abstraction of additional oxygen from the stream by the deposited sludge may produce conditions that are unanticipated and extremely objectionable. This question of the decomposition of sludge deposits is one of primary significance in the study of stream pollution and self-purification, and is a subject about which comparatively little has been known. The nature of the biological life which is operative, its biochemical oxygen demand, the rates of oxidation of the organic matter, and the various factors which influence this activity are matters of the greatest importance in interpreting existing conditions and forecasting conditions which may prevail in polluted waters. Under stream conditions the transformation of putrescible organic materials into more stable organic forms, and finally into inorganic and inert compounds, is desirably a process of oxidation, and it is one of the problems of sewage disposal by dilution to bring about such changes without the creation of septic conditions. Theoretically, sewage should be diluted sufficiently to allow reaeration and other agencies to supply the oxygen requirements of the polluting materials under critical conditions and prevent septicity while the organic wastes are being carried to bodies of water affording greater dilution. Deposits of sludge may upset such calculations. The *rate* of oxygen demand of the biological agencies at work in the deposited, as well as the suspended and dissolved, material is therefore

* Presented at the Seventeenth Annual Convention of the North Carolina Sewage Works Association, Wilmington, N. C., August 27, 1937.

the principal factor in determining the extent to which a stream may be safely loaded.

The phenomena attending the oxidation of sewage sludge deposits are probably not unlike those which prevail in the aerobic processes of sewage treatment. All such methods depend upon the presence of atmospheric oxygen to support aerobic life and effect the stabilization of organic matter without putrescence. Environmental factors which are favorable in one case may be favorable in all, and the active organisms are doubtless the same or similar ones with common life habits and requirements. It is reasonable to expect that general laws governing the activity of biological life in the aerobic decomposition of sludge banks can be applied in large measure to all aerobic processes of sewage treatment. The purpose of this study was to determine some of these basic factors, their effects and relationships. An effort was made to simulate the conditions which would be found in nature. The sludge chosen was freshly settled, and in its constituents represented deposits which might be expected in an average stream below a sewer outlet. Oxygen was applied dissolved in clean water, and the method of application approximated that of a flowing stream. The greatest care was taken in all technique and determinations to minimize experimental error.

Objectives of Experiment

The primary objectives of the investigation were the following:

1. The determination of the total biochemical oxygen demand of a typical sewage sludge for essentially complete stabilization, and the characteristics of this B.O.D. curve.
2. The effect of the concentration of dissolved oxygen in the supernatant water upon the rate of oxygen demand of the sludge.
3. The effect of the depth of the sludge deposit upon the rate of biochemical oxygen demand.
4. The effect of sunlight upon the organisms of aerobic decomposition, as reflected in the rate of oxygen demand.
5. The effect of temperature upon the rate of aerobic stabilization of the sludge.
6. The effect of salinity of the supernatant water upon the rate of oxygen demand.
7. The character and changes of the bacterial and protozoan life in sludges digested under different conditions of oxygen supply, sludge depth, light, temperature and salinity.

Methods and Technique

The measurement of oxygen used in the decomposition of sludge under different conditions was accomplished through a principle very simple in theory, but difficult in practice—that of measuring the depletion in the dissolved oxygen content of clean water flowing continuously and at uniform rates over the various samples of sludge deposited on

the bottoms of sealed containers. In Fig. 1 is shown a sectional view of such a container with its piping and appurtenances. Ordinary commercial glass carboys of twenty-liter capacity were employed as reaction chambers. The rubber stopper closing the neck of the carboy was bored to receive a thermometer and the three small glass tubes serving as influent pipe, effluent pipe and sludge sampling pipe. These connections through the stopper were sealed against air leaks by water held in a rubber collar around the neck of the carboy.

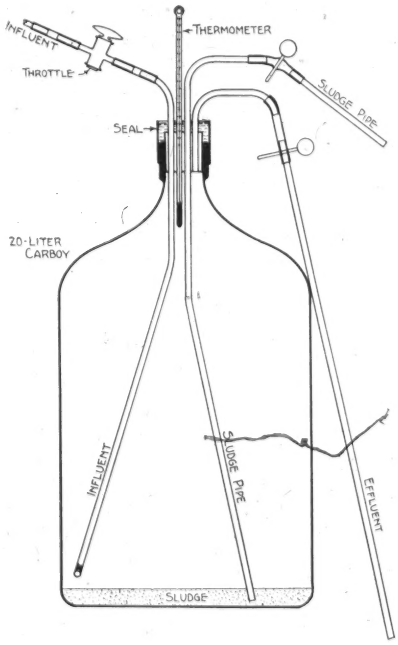


FIG. 1.—Aerobic sludge digestion apparatus.

At its upper end the influent tube was connected to a large enamel-lined tank in which aerated city tap water, free of chlorine or other purification chemicals, was stored and maintained at constant level and at practically uniform temperature and dissolved oxygen saturation values. A glass stopcock in this line served as a delicate flow regulator. Inside the carboy this influent line extended to a point about one inch above the surface of the sludge and was bent on a long radius to bring the discharge end near the wall of the carboy, with the tip bent at a 90 degree angle so as to discharge the water horizontally. With this

horizontal and tangential discharge the incoming water was distributed uniformly over the sludge surface, avoiding scour and short-circuiting.

The outlet tube was connected from the bottom of the carboy stopper and terminated below the bottom level of the bottle, so as to permit measurement of the discharge for calibration of the influent throttle and frequent checking of rates of flow. With this arrangement of inlet and outlet devices there was a continuous spiral and upward motion of water within the container. A sludge sampling pipe extended to the sludge level in the carboy. Being bent and movable, it permitted sludge sampling at any circumferential point and any vertical depth. Samples were taken by opening the pinch-cock on this line and closing the cock on the effluent line to build up hydrostatic pressure. Temperatures were obtained from the thermometers inserted into the carboys. The dissolved oxygen and hydrogen-ion concentrations of the supernatant water were obtained by determinations made at frequent intervals on samples of the influent and effluent of each carboy, collected without aeration. The oxygen consumption during any period of time was computed from the oxygen depletion of the water in passing through the container and the total flow for the period. All laboratory determinations were made in accordance with "Standard Methods" of the American Public Health Association.

Fourteen carboys of the type described were rigged up in a battery and so arranged and operated as to yield parallel results on the effects of such factors as sludge depth, oxygen concentration in supernatant, light, temperature and salinity. By comparing the results on various units or combinations of carboys any of these important factors could be studied. For the sake of accuracy, carboys A and 12, which contained very thin layers of sludge, were operated on a fill-and-draw principle; the others were run on the continuous-flow basis described above. The conditions under which each unit was designed to operate are given in Table I.

Carboys 1 to 5 inclusive, in which all conditions were constant, except the rate at which water was passed over the sludge, were used for study of the effect of concentration of O_2 in the supernatant water upon the rate of oxygen demand. Carboys 3, 6, 7, 8, 9 and 12, in which all conditions were constant except sludge depth, were employed for the determination of the effect of this factor upon the B.O.D. rate. Likewise Carboys 2 and 10 were used for the study of light effects, and Nos. 2 and 11, the latter of which was maintained at a higher temperature in an electric incubator, were observed for the effects of thermal difference. Carboys 2 and 13 were used to study the influence of a saline supernatant upon the rate of sludge decomposition.

Characteristics of Sludge and Water

The sludge used in this experiment was obtained from the Brockton, Massachusetts, sewage treatment plant and represents solids precipitated from the domestic and industrial wastes of a typical American

TABLE I.—*Conditions of Operation of Experimental Units*

Carboy No.	Sludge Depth, Cm.	Total Sludge, Grams	Light Conditions	Rate of Flow of Water, Liters per Hr.	Nature of Water	Av. Temp., ° C.
A	0.089	49	Daylight	Intermittent	Fresh	21.2
1	0.5	277	"	1	"	22.5
2	0.5	277	"	2	"	22.6
3	0.5	277	"	3	"	22.3
4	0.5	277	"	4	"	22.1
5	0.5	277	"	5	"	21.9
6	1.0	554	"	3	"	22.1
7	1.5	831	"	3	"	22.1
8	2.0	1108	"	3	"	21.9
9	4.0	2216	"	3	"	21.9
10	0.5	277	Darkened	2	"	22.6
11	0.5	277	Daylight	2	"	28.7
12	0.1	55	"	Intermittent	"	22.5
13	0.5	277	"	2	Salt	21.6

city. It was collected in a fresh condition and initial analyses showed the following characteristics:

Percentage dry solids	8.5
Percentage solids of organic nature	83.0
Total organic nitrogen, on dry basis	37,500 p.p.m.
Alkalinity, by methyl orange	800 p.p.m.
Alkalinity, by phenolphthalein	0
Hydrogen ion concentration	6.2 pH
Total bacteria on gelatin at 20° C.	24,300,000 per c.c.
Total bacteria on agar at 37° C.	14,000,000 per c.c.
Colon bacilli	500,000 per c.c.
Protozoa, in cubic standard units	220 per c.c.

The fresh water used for conveying oxygen to the sludge in the carboys was from the Cambridge, Massachusetts, municipal system, which is taken from surface sources and purified by plain sedimentation, chemical coagulation, rapid sand filtration and final chlorine sterilization. Its characteristics were as follows:

Color	0
Turbidity	0
Microorganisms	0
Total hardness	28 p.p.m.
Alkalinity, by methyl orange	19 p.p.m.
Chlorides	8 p.p.m.
Free chlorine	0
Hydrogen ion concentration	7.0 to 7.4
Biochemical oxygen demand, 5-day	0.2 to 0.5 p.p.m.
Dissolved oxygen	Saturated
Total bacteria on agar at 37° C.	1 to 2
Colon bacilli	0
Storage before use	2 to 3 days

The salt water used in Carboy 13 was prepared by dissolving ice cream salt in tap water to produce a salinity of 10,000 p.p.m. Cl, this salinity representing the average opposite Governor's Island in New York Harbor. This water had a total hardness of 153 p.p.m., an alkalinity of 31 p.p.m. and a pH value of 7.8. The bacterial content was the same as tap water. Sea water used for dilution purposes in conducting parallel B.O.D. tests as a check against the synthetic saline water was obtained from an unpolluted location near Nahant Beach and showed a chloride content of 19,000 p.p.m. Cl. It was filtered through paper, allowed to stand for three months in the laboratory and finally filtered through a Berkefeld filter before use.

Results

A. Total Biochemical Oxygen Demand of Sludge

Carboy A, previously described, was operated on an intermittent basis for the determination of the total oxygen demand and to study such characteristics of the demand curve as rates of demand, total time for stabilization and the fluctuations of rate during this time. The fill-and-draw principle permitted accurate determinations of the oxygen added to and withdrawn from the container, and yielded exact values of periodic and total demands. For this experiment the sludge depth was 0.089 cm., corresponding to 2.32 grams of dry solids, or 1.97 grams organic solids, the average temperature 21.19° C. and the average concentration of O_2 in the supernatant was 1.61 p.p.m. The resulting B.O.D. curve is shown in Fig. 2. During the first 48 hours the curve of oxygen demand rises abruptly due to the rapid oxidation of organic materials in solution and colloidal suspension, a general characteristic of such curves. Subsequently it flattens, and continues at a fairly uniform slope for about ten days. Then the rate of demand increases and the curve becomes concave upward until about the fifteenth day. This phenomenon, too, is characteristic, and is ascribed to the ascendency of nitrifying bacteria. However, the secondary stage is here not so pronounced as is usual in determinations on sewage and other liquid wastes, due to the masking effect of the slow but continuous conversion of sludge solids into forms that can be assimilated by the various forms of bacteria present. Following this stage the curve becomes only slightly concave downward and continues in a practically straight line with a decidedly upward trend until the demand is essentially satisfied at the end of 36 days. In this latter respect the curve departs from the ordinary B.O.D. characteristic, due to sustained conversion of solids.

For Connecticut River sludge banks Rudolfs (1) found first-stage 20° C., B.O.D. values ranging between 40,000 and 110,000 p.p.m. on the basis of volatile solids, the demands apparently varying with the character and age of the deposits. Clark (2) experienced first-stage values corresponding to a range of 21,000 to 173,000 p.p.m. at 20° C. on the basis of organic solids contained in the bottom deposits of the Charles

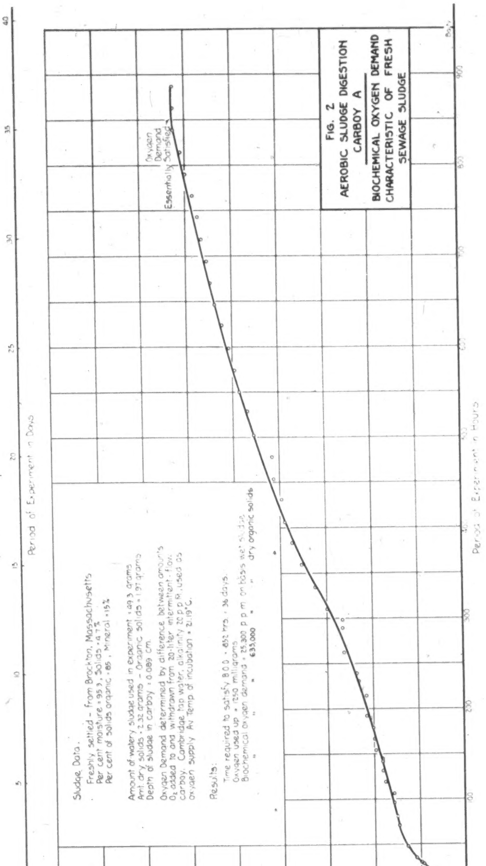


Fig. 2
AEROBIC SLUDGE DIGESTION
CARBOY A
BIOCHEMICAL OXYGEN DEMAND
CHARACTERISTIC OF FRESH
SEWAGE SLUDGE
Oxygen Demand Essentially Satisfied
Sludge Data.
Freshly settled – from Brockton, Massachusetts
Per cent moisture = 95.3, Solids = 4.7%
Per cent of solids organic = 85, Mineral = 15%
Amount of watery sludge used in experiment = 49.3 grams
Amt. dry solids = 2.32 grams – Organic solids = 1.97 grams
Depth of sludge in carboy = 0.089 cm.
Oxygen Demand determined by difference between amounts
O_2 added to and withdrawn from 20-liter intermittent-flow
carboy. Cambridge tap water, alkalinity 20 p.p.m., used as
oxygen supply. Av. Temp. of incubation = 21.19°C.
Results:
Time required to satisfy B.O.D. = 852 hrs. = 36 days.
Oxygen used up = 1250 milligrams
Biochemical oxygen demand = 25,300 p.p.m. on basis wet sludge
" " " = 633,000 " " " dry organic solids
Period of Experiment in Days
Period of Experiment in Hours
Biochemical Oxygen Demand – Milligrams of Oxygen

FIG. 2.

River when these were decomposed in fresh water. His average value was about 66,000 p.p.m. Theriault and McNamee (3), in connection with their studies on partially stabilized sludge from the artificial stream of the U. S. Public Health Service laboratory at Cincinnati, report first-stage 20° C. values of about 154,700 p.p.m. of total solids, corresponding presumably to about 240,000 p.p.m. on the basis of organic matter. The British Royal Commission (4) in its examination of muds from heavily polluted rivers found demands which, when converted to 20° C., varied between 23,000 and 173,000 p.p.m. of volatile solids. In the experiment of the author, using freshly precipitated sewage sludge which was unmixed with stream silt, the 10-day B.O.D. at 21.2° C. was 244,000 p.p.m. based on organic solids. After 36 days, when the stabilization of the film was essentially complete, the demand exercised had been 635,000 p.p.m. on a volatile solids basis.

B. Effect of Concentration of Oxygen in Supernatant Water on Rate of Biochemical Oxygen Demand

It seemed reasonable to expect that the amount of dissolved oxygen available in a stream or tidal estuary might have an important influence on the activity of the biological life at work in the sludge which carpets its bottom, and so regulate the rate at which oxygen is extracted from the water for the support of this life. Theriault (5) has stated in connection with his investigation of the first-stage characteristics of the deoxygenation curve that, within wide limits, the rate of oxygen demand is quite independent of the amount of dissolved oxygen present. However, Theriault, McNamee and Butterfield (6) express the conclusion that in longtime B.O.D. tests nitrification is adversely affected when the dissolved oxygen falls to 2 p.p.m. or less, corresponding to a depletion of 75 per cent or more. Heukelekian (7) in his study of the Raritan River appears to confirm this belief, and states that nitrification increased with D.O. concentrations of 80 per cent saturation, or more, while a marked decrease was noted when the oxygen content dropped to 60 per cent saturation, and below. This latter effect he attributes to reduction in localized anaerobic zones of the river. Since the processes of oxidation of both the carbonaceous and nitrogenous materials are operative and significant in the long-time decomposition of sludge deposits, it was hoped that the technique of this experiment might throw some additional light on this important question.

Carboys 1, 2, 3, 4 and 5 used in this study were identical except for the rate of water flow, which was varied in the several containers to produce widely different values of dissolved O_2 in the water overlying the sludge. The concentration was at times reduced to 0.1 or 0.2 p.p.m. in No. 1, while the effluent from No. 5 often showed more than 6.0 p.p.m. After 36 days of continuous operation, the flow of water was stopped and the carboys were allowed to stand in a septic condition for 72 days, so that subsequent rates of oxygen demand could be observed and compared. The sludge depth in the five carboys was 0.5 cm. They were

all exposed to daylight and fresh water was used as the oxygen vehicle. The average temperature of the several containers varied from 21.9° to 22.6° C.

The results of this study are shown graphically by the curves of Fig. 3. For the purpose of comparison, the mass curves of oxygen demand for the five carboys have been plotted with elapsed time as abscissae, while the ordinates represent the cumulative amounts of oxygen used. The slope of a curve at any point would represent the rate of demand at that time. Here the *total* B.O.D. of the sludge was not a matter of interest; the *relative* demand under different conditions of oxygen supply was the subject of study. For this reason, and to conform to the requirements of the continuous-flow technique it was necessary to neglect the initial oxygen demands. Flow was started through the carboys 24 hours before O_2 determinations were begun, which accounts for the absence of an abrupt rise in the curves at the beginning. It is observed that the curves constitute a close sheaf of approximately parallel lines, having uniform slope and, therefore, indicating fairly constant rates of O_2 demand. While they are not coincident, the curves diverge comparatively little, and it is interesting to note that they cross and recross each other during the experiment. Such variations may well be due to slight variations in the character of the sludge samples and to minor experimental errors. The important observation is that the amounts of O_2 used up in each of the containers were essentially the same within the period of 852 hours. The ordinates at this point show the lowest O_2 consumptions (3,413 and 3,415 mg.) in Carboys 1 and 5, the ones with lowest and highest dissolved oxygen concentrations, respectively. Next is No. 4, then No. 2 and the highest demand is in No. 3. The scatter of values is within 6 per cent of the mean, a deviation which is well within the range of expectancy.

After a 72-day period of septicity, the curves show practically the same slope as before. This indicates that a sludge deposit lying under a deoxygenated blanket of water for a period of time may undergo partial anaerobic digestion, but when oxygen is again available the aerobic processes are resumed immediately and proceed at essentially the same rate as before.

It appears from these results that the aerobic processes of sludge-bank decomposition proceed at the same rate regardless of the concentration of oxygen in the overlying water, provided absolute depletion is avoided. It seems reasonable that, insofar as oxygen requirements are concerned, this finding might have application to the aerobic processes of sewage treatment, such as activated sludge and trickling filters.

C. Effect of Sludge Depth on Rate of Oxygen Demand

The purpose of this study was to determine the relationship between the depth of sewage sludge deposit and the rate at which oxygen is absorbed from the overlying water. Carboys having sludge depths of 0.1, 0.5, 1.0, 1.5, 2.0 and 4.0 centimeters were employed. Since it was

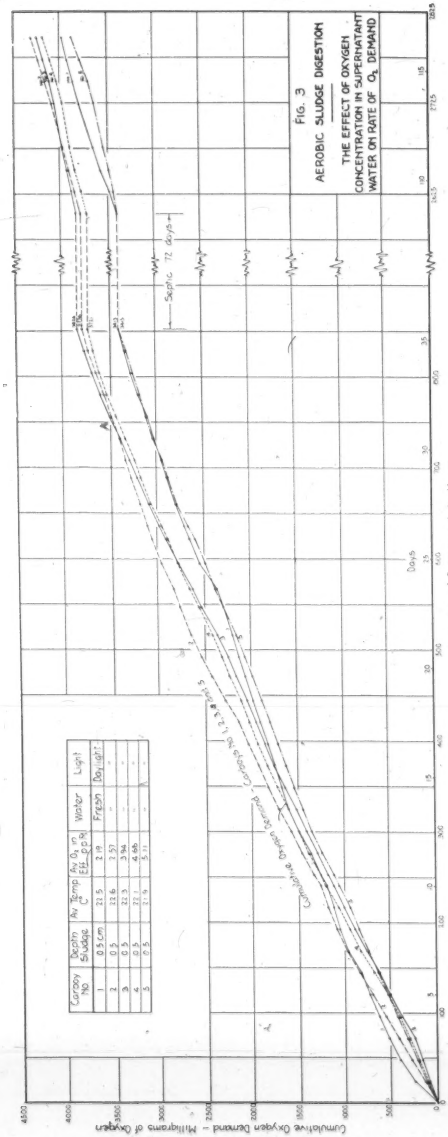


FIG. 3
AEROBIC SLUDGE DIGESTION
THE EFFECT OF OXYGEN CONCENTRATION IN SUPERNATANT WATER ON RATE OF O_2 DEMAND
Septic 12 days
Cumulative Oxygen Demand – Milligrams of Oxygen
Period of Experiment in Hours
Days
Curves No. 1, 2, 3, 4 & 5
Corresponding to Flasks Numbered
Curvey No. | Depth Sludge | Av. Temp C° | Av. O2 in Eff. p.p.m. | Water Frozen | Light
1 | 0.5 cm | 21.5 | 2.19 | -- | Daylight
2 | 0.5 | 21.6 | 3.97 | -- | --
3 | 0.5 | 21.3 | 3.94 | -- | --
4 | 0.5 | 21.1 | 4.48 | -- | --
5 | 0.5 | 21.9 | 5.11 | -- | --

Fig. 3.

found that the O_2 concentration of the supernatant has no influence on the rate of demand, the average results for carboys 1 to 5 were used for the 0.5 cm. depth. As in the other studies, water was passed through the containers for 852 hours, flow was then stopped for 72 days, and afterwards resumed for a period. The conditions prevailing in these carboys and the significant results are presented graphically in Fig. 4. As in the previous experiment these curves represent the cumulative O_2 consumption of the various units, with their slopes indicating rates of demand. In Table II are shown the cumulative amounts of oxygen used and the average rates of oxygen demand for the several units during the initial 852-hour period.

TABLE II.—*Variations of Oxygen Demand with Sludge Depth at 22° C.*

Carboy No.	Sludge Depth	Cumulative Oxygen Used	B.O.D. Rate Mg. of O_2 per Sq. Meter Sludge Area
12	0.1 cm.	1,079 mg.	545
1–5	0.5 cm.	3,630 mg.	1,840
6	1.0 cm.	5,637 mg.	2,890
7	1.5 cm.	6,727 mg.	3,450
8	2.0 cm.	7,344 mg.	3,765
9	4.0 cm.	10,075 mg.	5,170

It is seen that the amounts and rates of oxygen used during the same period were not in direct proportion to the sludge depths. Increased depths demanded more oxygen, but the relationships were not arithmetical. A sludge layer of 0.5 cm. thickness required only 3.36 times as much as the 0.1 cm. layer. Between the 0.5 and 1.0 cm. depths the ratio was 1.55; between 1.0 and 2.0 cm. the ratio was 1.3; and between 2.0 and 4.0 cm. thicknesses the ratio was 1.37.

To show more clearly the relationship, a curve is given in Fig. 5 which is prepared by plotting the sludge depths in centimeters against the average rates, in milligrams per square meter per day, of oxygen used during the 852 hour period of aerobic action. This graph has a shape approximating that of a parabola; an equation of the general form, $y = ax^b$; and plots as practically a straight line on logarithmic paper. Although the curve is not a true parabola, the equation which expresses the relationship at 22° C. is approximately:

$$Y = 2700\, X^{0.485}$$

where X is the depth of the sludge in centimeters and Y is the rate of oxygen demand, in milligrams per day per square meter of sludge surface. The rates of O_2 demand prevailed quite uniformly throughout the period of the experiment. Aerobic decomposition is thus shown to be primarily a surface phenomenon, the stabilized materials being transformed into colloidal materials which pass away and leave fresh surfaces of undigested sludge exposed until the whole mass is trans-

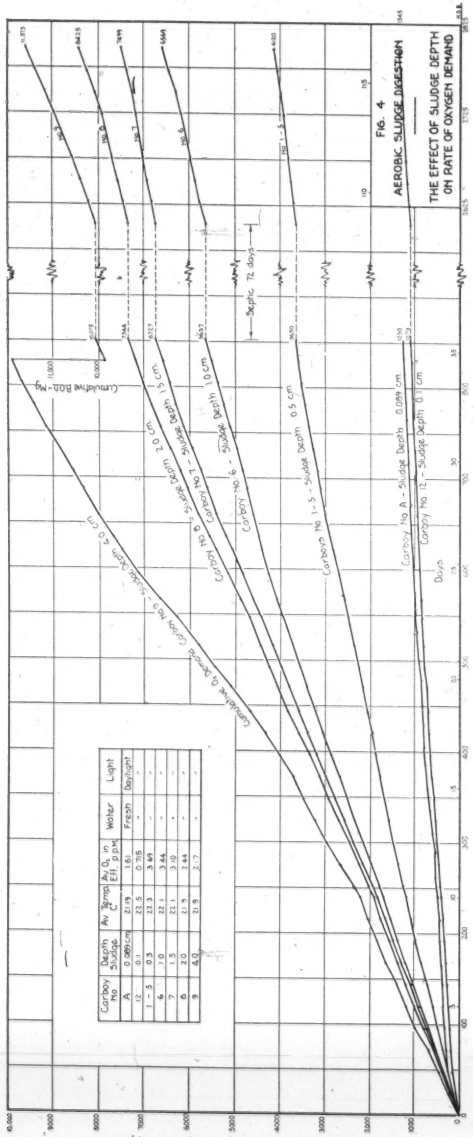


FIG. 4
AEROBIC SLUDGE DIGESTION
THE EFFECT OF SLUDGE DEPTH ON RATE OF OXYGEN DEMAND
Cumulative Oxygen Demand of Sludge - Milligrams of Oxygen
Period of Experiment in Hours
Days
Carboy No A - Sludge Depth 0.099 cm
Carboy No 12 - Sludge Depth 0.1 cm
Carboys No 1-5 - Sludge Depth 0.5 cm
Carboy No 6 - Sludge Depth 1.0 cm
Carboy No 7 - Sludge Depth 1.5 cm
Carboy No 8 - Sludge Depth 2.0 cm
Carboy No 9 - Sludge Depth 4.0 cm
Septic 72 days
Curve line B.O.D. - Mg
Carboy No | Depth Sludge | Av. Normal | Av. O2 in Eff. p.p.m. | Water | Light
A | 0.099 cm | 21.19 | 1.61 | Fresh | Daylight
12 | 0.1 | 23.5 | 3.95 | - | -
1 - 5 | 0.5 | 23.5 | 3.45 | - | -
6 | 1.0 | 22.1 | 3.44 | - | -
7 | 1.5 | 23.1 | 3.10 | - | -
8 | 2.0 | 21.5 | 3.44 | - | -
9 | 4.0 | 21.9 | 2.7 | - | -

Fig. 4.

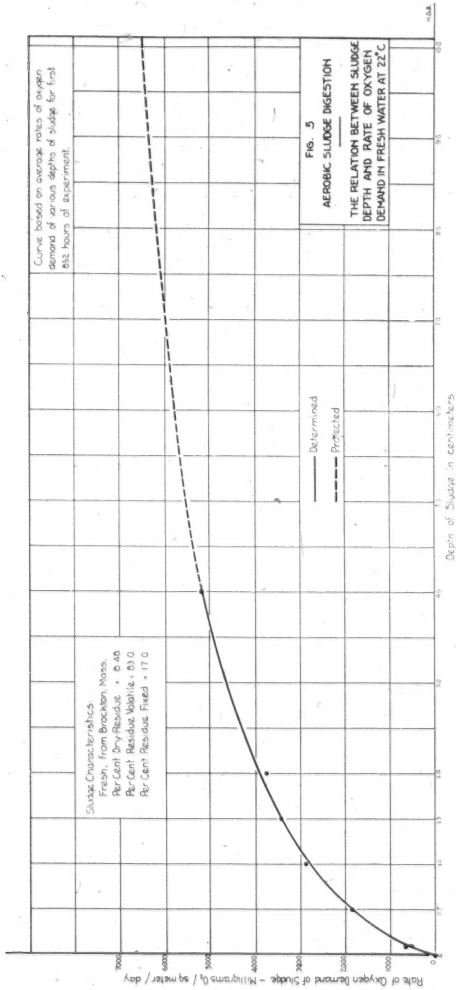

Curve based on average rates of oxygen demand of various depths of sludge for first 852 hours of experiment.
Sludge Characteristics
Fresh, from Brockton, Mass.
Per Cent Dry Residue = 6.48
Per Cent Residue Volatile = 53.0
Per Cent Residue Fixed = 47.0
Determined
Projected
FIG. 5
AEROBIC SLUDGE DIGESTION
THE RELATION BETWEEN SLUDGE DEPTH AND RATE OF OXYGEN DEMAND IN FRESH WATER AT 22° C
Rate of Oxygen Demand of Sludge - Milligrams O2 / sq meter / day
Depth of Sludge in centimeters

FIG. 5.

formed. In case of the deeper layers it was observed that there is actually some increase in the rates of O_2 demand with time. This is due to gas formation from anaerobic digestion in the lower portions of the deposit and its ebullition, which caused disturbances of the surface, with the result that new sludge and greater areas were exposed to the water and subjected to aerobic biological action.

Again it is interesting to note that with all depths of sludge the rates of O_2 demand under aerobic decomposition are not appreciably affected by an intervening period of septic action.

During the experiment it was observed that sludge layers of depths of one centimeter and less maintained themselves without disruption, while deposits of 1.5 cm. and more were from time to time stirred up and their surfaces broken by the upheaval of gases formed by anaerobic digestion in their lower layers. The oxygen of the supernatant water is not diffused to any great depths in sufficient quantities to support aerobic life. Even in thin blankets of organic river deposits, gas-forming anaerobes are at work in the lower layers at the same time oxidation processes are taking place at the sludge surface. It is indicated that the critical depth for stability of fresh sludge deposits is not more than one centimeter—the limit of oxygen diffusion—and that the greater rate of oxygen absorption by deeper deposits is due in part to the oxygen demand of the gases evolved from anaerobic processes, and in part to the stirring action of these gases which bring new and greater sludge surfaces into contact with the water.

D. Effect of Sunlight on Rate of Oxygen Demand

It was considered possible that light might have either a direct effect upon the types and activity of the bacterial and protozoan agencies of decomposition, or an indirect effect on the photosynthesis of accompanying algal forms of life, that would be measurable in the oxygen requirements of sludge digested under conditions of light and darkness. In its practical application to stream pollution problems this question is important; it is desirable to know the relative amounts of oxygen from atmospheric sources required by sludge deposits digesting in open sunlight, in shade, at great depths, or under the water of turbid or colored streams.

In the experiment one carboy, No. 10, was completely darkened and operated in parallel with the series, Nos. 1 to 5, in which all influencing factors were identical, except light conditions. The results of this comparison are shown graphically by the curves of cumulative oxygen demand in Fig. 6. At the end of 852 hours the oxygen consumption under daylight conditions was 3,630 mg., while, in the absence of light, the same amount of sludge had demanded 3,601 mg.—a remarkable agreement. At the end of the experiment, following the intervening period of septicity, the total demand under each condition was exactly the same, 4,120 milligrams. Bacterial and microscopic examinations failed to show any great difference in the fauna and flora living under the dif-

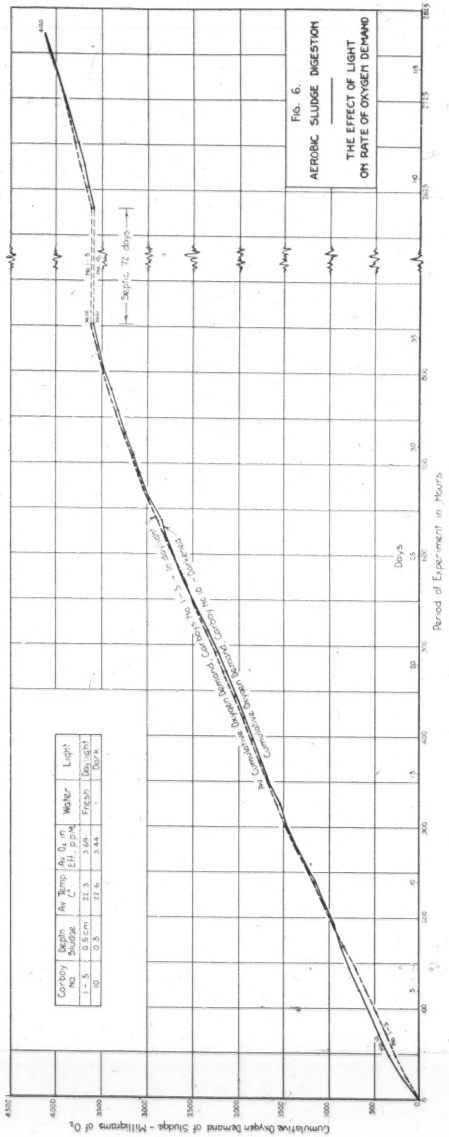


Fig. 6.
AEROBIC SLUDGE DIGESTION
THE EFFECT OF LIGHT ON RATE OF OXYGEN DEMAND
Carboy No. | Depth Water | Av. Temp. C° | At. O2 in Ext. p.p.m. | Water | Light
1 - 5 | 0.5 cm | 22.3 | 3.69 | Fresh | Daylight
10 | 0.5 | 22.6 | 3.44 | | Dark
Septic 72 days
Cumulative Oxygen Demand of Sludge - Milligrams of O2
Period of Experiment in Hours
Days

Fig. 6.

ferent light conditions. No vegetable forms of organisms, subject to photosynthesis, were found at any time in any of the carboys. This, of course, was due to the limited period of retention of the water in the containers. Under actual stream conditions, where algal forms are known to grow in abundance with favorable factors of oxygen, sunlight, time, temperature and food, their contribution of oxygen would doubtless be measurable, and of importance in the economy of the stream. Many investigators have shown the significance of the oxygen contribution made to streams and lakes by algal forms of life. Purdy (9) has recently demonstrated that, under certain conditions, the oxygen derived from this source is sufficient to supply the demand of the aerobic bacteria at work in a heavily polluted water.

E. Effect of Temperature on Rate of Oxygen Demand

It is well known that temperature is one of the most important environmental factors governing most forms of biological life. Investigators of the United States Public Health Service (5), (10), (11), (12), (13), (14) and others (15), (16), have made extensive studies on the relationships between temperature and rates of deoxygenation, as reflected in the standard B.O.D. determination. From masses of experimental data, a formula, generally known as the Phelps formula (10), has been derived to express this relationship. It was the objective of our study to determine the effect of temperature, within narrow limits, on the rate of aerobic sludge decomposition and to see whether this process conformed to the basic laws previously deduced from related experiments.

One carboy, No. 11, was enclosed in an electric incubator, together with a coil of water-supply piping, and maintained at an average temperature of 28.7° C. Results were compared with those from the series, Nos. 1 to 5, operated at 22.3° C., and having all effective conditions identical, except the temperature factor. Due to lack of additional incubators of large capacity, the experiment was unfortunately limited to these two temperatures. Later studies will include a greater range.

The results are shown graphically in the cumulative oxygen demand curves of Fig. 7. These curves are of generally uniform slope and at the end of 852 hours show the amount of oxygen used at 22.3° C. as 3,630 mg., while at 28.7° C. the consumption was 5,867 mg. Following the period of septicity the relative rates were the same. The ratio of demand between these two temperatures is 1.62.

The formula proposed by Phelps (10) is based upon the assumption that the rate of deoxygenation at any time is directly proportional to the amount of organic matter present in a B.O.D. sample, and is as follows: $X = L_a (1 - 10^{-kt})$, where X is the oxygen demand for t days; L_a is the oxygen absorbed during the first, or carbon-oxidation, stage; K is the deoxygenation constant, depending on temperature; and t is the time of incubation in days. The value of the deoxygenation con-

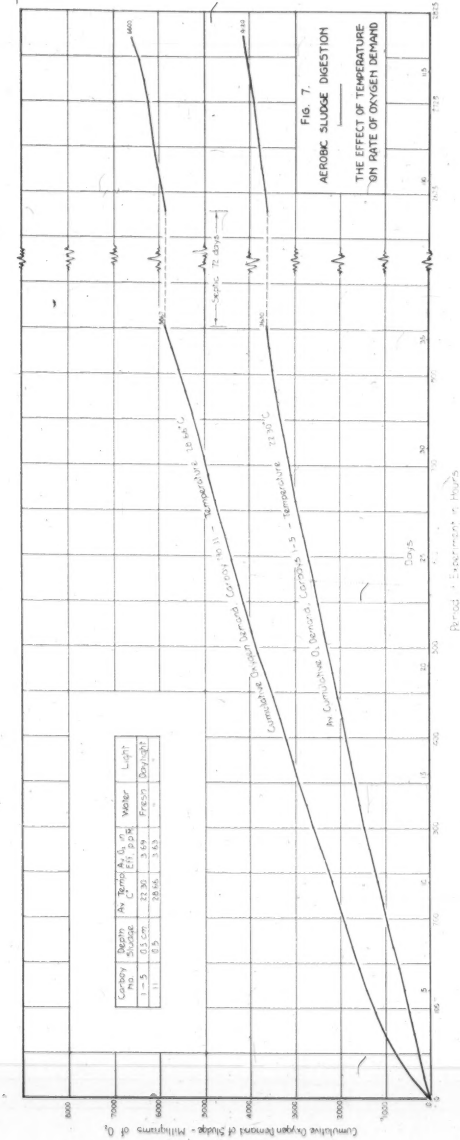


Fig. 7.
AEROBIC SLUDGE DIGESTION
THE EFFECT OF TEMPERATURE ON RATE OF OXYGEN DEMAND
Carboy No. | Depth of Sludge | Av. Temp. | Av. O_2 in H_2O | Water | Light
1 – 5 | 0.5 cm. | 22.30 | 3.69 | Fresh | Daylight
11 | 0.5 | 28.66 | 3.63
Cumulative Oxygen Demand, Carboys 1-5 – Temperature 22.30°C
Cumulative Oxygen Demand, Carboy 11 – Temperature 28.66°C
Aerobic 72 days
Cumulative Oxygen Demand of Sludge - Milligrams of O_2
Period of Experiment in Hours
Days

Fig. 7.

stant, K, for different temperatures varies according to the following relationship: $K_T = K_{20}\,(1.047^{T-20})$, where K_T is the constant at any temperature, $T°$ C.; and K_{20} is the value of the constant at 20° C., which equals 0.100.

Assuming an arbitrary value of $(L_a)_{20} = 100$ for comparative purposes, using the value of $K_{20} = 0.100$ and a value of t (the average time of exposure of each colloidal particle with the water passing through the carboy) equal to 0.5 day, the values of $(L_a)_T$, K_T and X_T were computed for temperatures between 10° and 40° C. From these relative values, the observed value for the rate of oxygen demand at 22.3° C. was adjusted to give the rates at which O_2 *would have been* absorbed by a like thickness of sludge at these various temperatures according to the Phelps formula. Figure 8 shows these values plotted as a curve passing through the observed value at 22.3° C. The observed value of rate of O_2 demand at 28.7° C. is seen to fall slightly off the theoretical curve. It appears, therefore, that the relationship between temperature and the rate of aerobic decomposition of sludge deposits is expressed with reasonable accuracy by the biological formula proposed by Phelps.

F. Effect of Salinity of Supernatant Water on Rate of Oxygen Demand

When it is considered that the sewage from perhaps 10,000,000 people in this country is discharged in a raw condition, or with the most meagre treatment, into tidal estuaries, the question of the effect of the salt water upon the ultimate decomposition of the resulting sludge deposits becomes one of great sanitary importance. Most tidal waters provide a favorable condition for the settlement of suspended matter. Opinions of sanitarians have differed widely regarding the effect of salinity upon the biological processes; some experts have maintained that oxygen is abstracted more rapidly under salt water conditions and that septicity occurs more readily in salt water with a given amount of organic pollution. Clark (2) reports an average first-stage oxygen demand of Charles River mud of 76 grams per kilogram of volatile matter when incubated under fresh water at 26.7° C., while the same deposit incubated for the same time and at the same temperature under salt water required an average of 143 grams of O_2 per Kg. of volatile solids. The Metropolitan Sewerage Commission (17) expressed the view that sewage solids settle more readily in salt water than in fresh water and that fresh water will dispose, in a normal manner, of more sewage than sea water. Heukelekian (7) in his study of the Raritan River observed that admixture of sea water below Perth Amboy caused a sharp decrease in nitrification. The purpose of this study was to observe the effect of salinity on the biological agencies of aerobic decomposition as reflected in the relative rates of oxygen consumption under fresh and salt conditions.

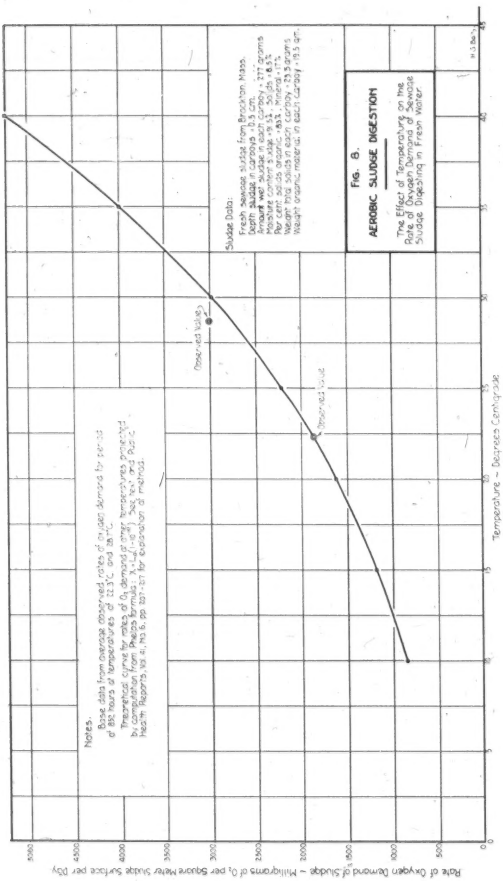

Rate of Oxygen Demand of Sludge - Milligrams of O2 per Square Meter Sludge Surface per Day
Temperature - Degrees Centigrade
Observed Value
Observed Value
Notes.
Base data from average observed rates of Oxygen Demand for periods of 66 hours at temperatures of 12.3°C and 28.1°C.
Theoretical curve for rates of O2 demand at other temperatures prepared by Prof. Earle B. Phelps, Sanitary Engineering Section, U.S. Public Health Reports, Vol. 41, No. 6, pp. 327-361 for explanation of method.
Sludge Data:
Fresh sewage sludge from Brockton Mass.
Depth sludge in carboys = 0.5 cm.
Surface area of sludge = 177 sq. cm.
Moisture content of sludge = 91.5%
Per cent solids organic = 63.1% mineral = 36.9%
Weight of sludge in each carboy = 1500 grams
Weight organic material in each carboy = 69.5 gr.
Fig. 8.
AEROBIC SLUDGE DIGESTION
The Effect of Temperature on the Rate of Oxygen Demand of Sewage Sludge Digesting in Fresh Water

Fig. 8.

Carboy No. 13 was operated with salt water, having a chloride content of 10,000 p.p.m. Cl, as the oxygen-carrying vehicle. The series of carboys, Nos. 1 to 5, using fresh water, but with all other effective conditions identical, was operated as a control. The results of this comparison are shown by the cumulative oxygen demand curves of Fig. 9. These curves are of fairly uniform slope, and at the end of 852 hours the sludge in the salt-water container had used 1,980 milligrams of oxygen, while the control series had used 3,630 milligrams. The ratio between the two was 1.83. A long period of septic action did not appear to affect the relative rates when the aerobic experiment was resumed.

Since it was possible that the synthetic sea water prepared from crude salt did not truly represent natural sea water, a series of B.O.D. tests was conducted in the standard manner, using strained fresh sewage as the pollutional material and with parallel series of samples prepared identically with dilutions of tap water and clean sea water of 19,000 p.p.m. Cl salinity. Two groups of the samples of each character were incubated simultaneously and in the same incubators at 20° C. and 25° C. for a period of 50 days. Periodically sub-samples were removed for oxygen analysis. The results obtained were used for the construction of comparative longtime B.O.D. curves, which are presented in Fig. 10. The shapes of these characteristics are interesting, particularly the primary and secondary phases of demand in the fresh-water curves, and the almost complete absence of any indication of secondary nitrification phase in the salt-water curves. At the end of the 50-day period the oxygen depletions of the identical samples were as follows:

Character of Dilution	Oxygen Depletion	
	At 20° C.	At 25° C.
50 : 1 Stabilized Tap Water	9.71 p.p.m.	10.30 p.p.m.
50 : 1 Clean Sea Water	3.73 p.p.m.	4.42 p.p.m.

Here it is observed that the amount of oxygen used by a given amount of organic matter in fresh water was about 2.5 times that used in salt water for the same period. This ratio is even greater than that observed in the carboy experiment, due to the higher salinity of the dilution water, and confirms the effect of salt upon the B.O.D. rate. Other parallel tests were conducted, using fresh, synthetic and sea water as dilutants, which verified the carboy results and indicated, further, that the B.O.D. rate is almost in inverse proportion to the salt concentration of the supernatant water.

These significant results may be interpreted as meaning that, other conditions being equal, a greater amount of deposited sludge may underly salt than fresh water without depleting the dissolved oxygen supply. In a location such as New York harbor the ratio would be about 1.8 to 1.0 if the waters carried equal amounts of dissolved oxygen. However, when differences in O_2 saturation values and reaeration rates

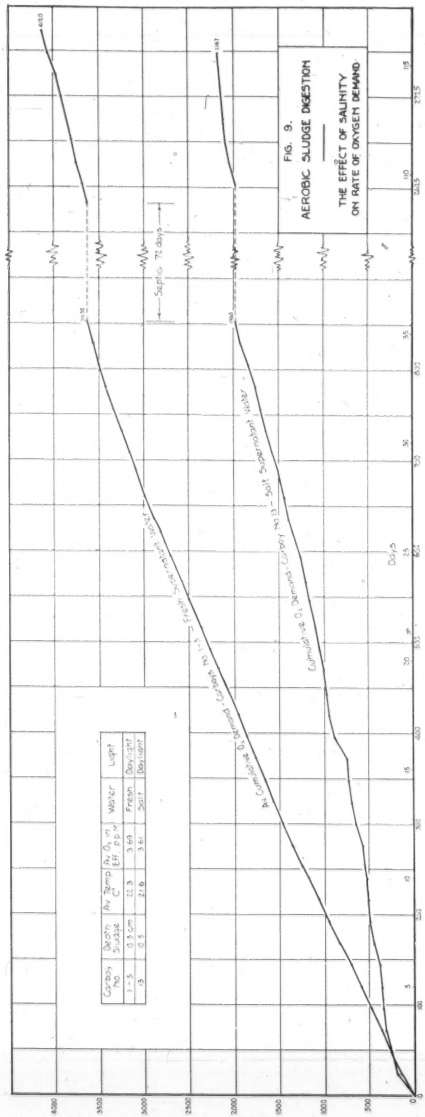


FIG. 9.
AEROBIC SLUDGE DIGESTION
THE EFFECT OF SALINITY ON RATE OF OXYGEN DEMAND
Cumulative Oxygen Demand of Sludge - Milligrams of O2
Period of Experiment in Hours
Days
Septic 72 days
Cumulative O2 Demand Curve No 1 = Fresh Supernatant Water
Cumulative O2 Demand Curve No 13 = Salt Supernatant Water
Curve No | Depth Sludge | Av Temp C° | Av O2 in Ppm | Water | Light
1 to 5 | 0.5 cm | 17.3 | 3.69 | Fresh | Daylight
13 | 0.5 | 17.8 | 3.62 | Salt | Daylight

FIG. 9.

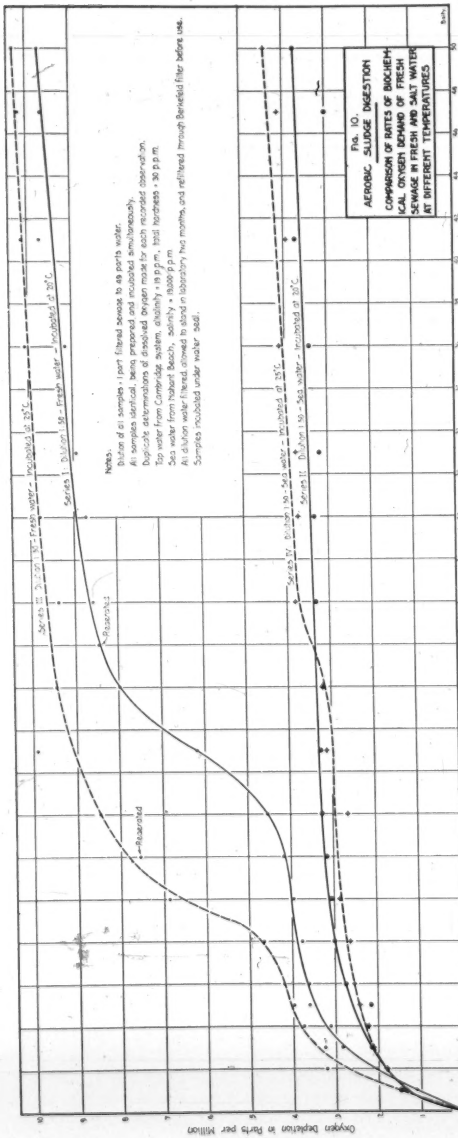

Oxygen depletion in parts per million
Period of Experiment—Days
Series I Dilution 1/6 – Fresh water – Incubated at 20°C
Series II Dilution 1/6 – Fresh water – Incubated at 30°C
Series III Dilution 1/6 – Sea water – Incubated at 20°C
Series IV Dilution 1/6 – Sea water – Incubated at 30°C
Aerated
Not Aerated
Notes.
Dilution of all samples 1 part filtered sewage to six parts water.
All dilution waters were prepared and incubated simultaneously.
At regular intervals determinations of dissolved oxygen made for each recorded observation.
Top water from Contervalle system, alkalinity = 110 p.p.m., total hardness = 360 p.p.m.
Sea water from Hobart Beach, salinity = 18000 p.p.m.
All dilution water filtered, allowed to stand in laboratory two months, and refiltered through Berkefeld filter before use.
Samples incubated under water seal.
FIG. 10.
AEROBIC SLUDGE DIGESTION
COMPARISON OF RATES OF BIOCHEMICAL OXYGEN DEMAND OF FRESH SEWAGE IN FRESH AND SALT WATER AT DIFFERENT TEMPERATURES

Fig. 10.

are considered, the relative effects on the dissolved oxygen content of the water of a given deposit of sludge would be in the approximate ratio of 1.6 to 1.0. On the other hand, under conditions of heavy pollution, the formation of sludge banks would be more rapid in salt than in fresh water, other conditions being equal. The precipitated organic sediment must eventually undergo decomposition of some type. So, it would continue to accumulate in larger and larger volumes, with the aerobic and anaerobic processes of digestion, diminished in rate by the salinity of the water, unable to keep pace with the rate of deposition. Some light may be thrown upon the scientific reason for this phenomenon by the observations on biological life which follow—particularly the absence of protozoan forms in the salt water.

G. Bacterial and Protozoan Life in Sludge During Decomposition

It was desirable to have full knowledge of the biological life existing in the several containers under the varying conditions. However, the author was without assistance and the attention and numerous determinations involved in this continuous experiment made it impossible to engage in the tedious and time consuming work of identifying and differentiating the various species of bacteria and protozoa. The general and simpler bacteriological and microscopic examinations were conducted throughout the experiment. At intervals of two or three days determinations were made of the total bacteria counts on gelatin at 20 C. and on agar at 37° C., the *B. Coli* population and the protozoan life. It was considered sufficient to make these studies on only one carboy representing each of the primary conditions.

The results of the total bacteria counts on nutrient gelatin incubated at 20° C. for 48 hours for Carboys 6, 10, 11 and 13 are shown by the curves of Fig. 11. Time is represented as abscissae plotted on a natural scale, while the counts are plotted as ordinates on a logarithmic scale. At the beginning, each sludge showed a total count of 24,350,000 colonies per cc. After 72 hours the count was greatly reduced, due to the readjustment of the bacterial life. Subsequently the population of all samples increased rapidly until saturation values were reached. The curves then flattened out and remained essentially horizontal, except for some erratic variations, until the end of the test. The average counts of the sludges kept at room temperature and under daylight, darkened and saline conditions were about the same, 60 million per c.c. The high-temperature container showed an average count of about 110 million per c.c.

Figure 12 shows the corresponding total bacterial counts on nutrient agar incubated for 24 hours at 37° C. Initially all the sludges contained 14,000,000 bacteria per c.c. As in the previous case, the agar counts indicated a very great reduction of 37° organisms at the end of 72 hours, except in the high temperature container. Subsequently the counts mounted rapidly, and were quite erratic throughout the experiment. Toward the end of the period there was an appreciable decrease

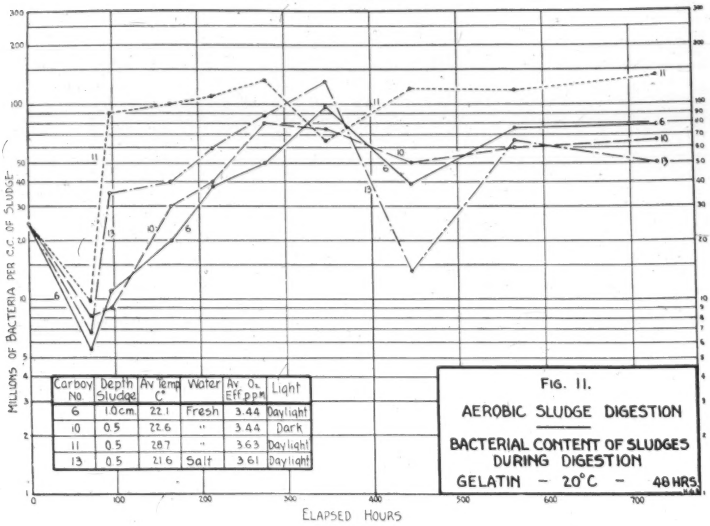

MILLIONS OF BACTERIA PER C.C. OF SLUDGE
ELAPSED HOURS
Carboy No. | Depth Sludge | Av. Temp C° | Water | Av. O2 Eff. ppm | Light
6 | 1.0 cm. | 22.1 | Fresh | 3.44 | Daylight
10 | 0.5 | 22.6 | " | 3.44 | Dark
11 | 0.5 | 28.7 | " | 3.63 | Daylight
13 | 0.5 | 21.6 | Salt | 3.61 | Daylight
FIG. 11.
AEROBIC SLUDGE DIGESTION
BACTERIAL CONTENT OF SLUDGES DURING DIGESTION
GELATIN - 20°C - 48 HRS.

FIG. 11.

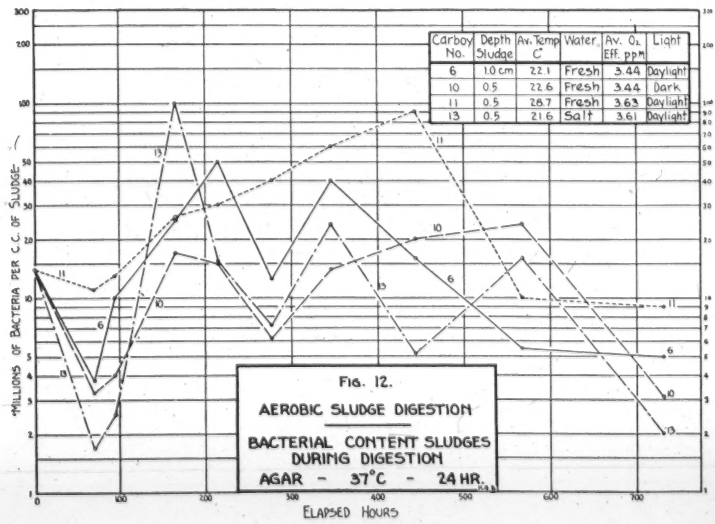

MILLIONS OF BACTERIA PER C.C. OF SLUDGE
ELAPSED HOURS
Carboy No. | Depth Sludge | Av. Temp C° | Water | Av. O2 Eff. ppm | Light
6 | 1.0 cm | 22.1 | Fresh | 3.44 | Daylight
10 | 0.5 | 22.6 | Fresh | 3.44 | Dark
11 | 0.5 | 28.7 | Fresh | 3.63 | Daylight
13 | 0.5 | 21.6 | Salt | 3.61 | Daylight
FIG. 12.
AEROBIC SLUDGE DIGESTION
BACTERIAL CONTENT SLUDGES DURING DIGESTION
AGAR - 37°C - 24 HR.

FIG. 12.

in all carboys. The high-temperature unit had an average population during the period of about 30 million per c.c.; the others did not vary widely or significantly, and averaged about 15 million organisms per c.c.

Figure 13 shows the fate of colon bacilli during the period of the experiment. At the beginning the sludge contained 500,000 *B. Coli* per c.c. The die-away was very rapid in Nos. 6, 10 and 11, a reduction from the initial value to 100 per c.c. taking place within the first 200 hours. The mortality in these three units continued at a high rate until the end of the test, when it was practically complete. In the salt-water carboy, however, it is significant that the *B. Coli* suffered a relatively slow and small diminution to 5,000 organisms per c.c. at the end. It is apparent that some preservative or vitalizing effect is exercised by saline water. Hotchkiss (18) states that sodium chloride begins to exert a toxic action on *B. Coli* between one and two molar concentrations (35,000 to 70,000 p.p.m. Cl). Heukelekian (7) found that 7.5 per cent of sea water mixed with the water of a polluted stream (about 1,400 p.p.m. Cl) exercised no appreciable effect on the *B. Coli* population.

In Fig. 14 are shown the results of microscopic examination of the sludge of the four test carboys during the experiment. Values are expressed in cubic standard units of organisms. At no time were any algal forms of life identified in the samples, due to the flow conditions in the carboys, but in some cases as many as fifty species of protozoan organisms were found working simultaneously in the sludges. Initially there were present in the sludge about 1,000 organisms per c.c. of various flagellate protozoa, the majority of which were identified as *Cryptoglena*, comprising a volume of about 220 cubic standard units per c.c. In Carboys 6, 10 and 11 there was an early rapid increase in number of organisms, and during the period of the test the progression in forms from the smallest unicellular flagellates to the larger infusoria was most interesting. The various species would often succeed each other very rapidly. One form would become well established, only to be destroyed within a small period of time by the ravages of a more potent organism which had gained the ascendency. This accounts for the great variations in the curves of Fig. 14. The average protozoan content of the sludges under fresh water conditions was about 20,000 cubic standard units per c.c.

The most significant observation was the disappearance within the first 24 hours of all forms of protozoan life from the salt-water carboy. At no later time did this form of life reappear. Butterfield, Purdy and Theriault (8) have shown that the activity of protozoa in a B.O.D. sample exercises an important influence on the rate of deoxygenation, through the stimulation of bacterial multiplication to restore populations depleted by the ravages of the hungry animal forms. It is possible that the absence of protozoa in the salt-water sample allowed the bacterial population to become saturated and static, with the result that their oxygen requirements were lowered.

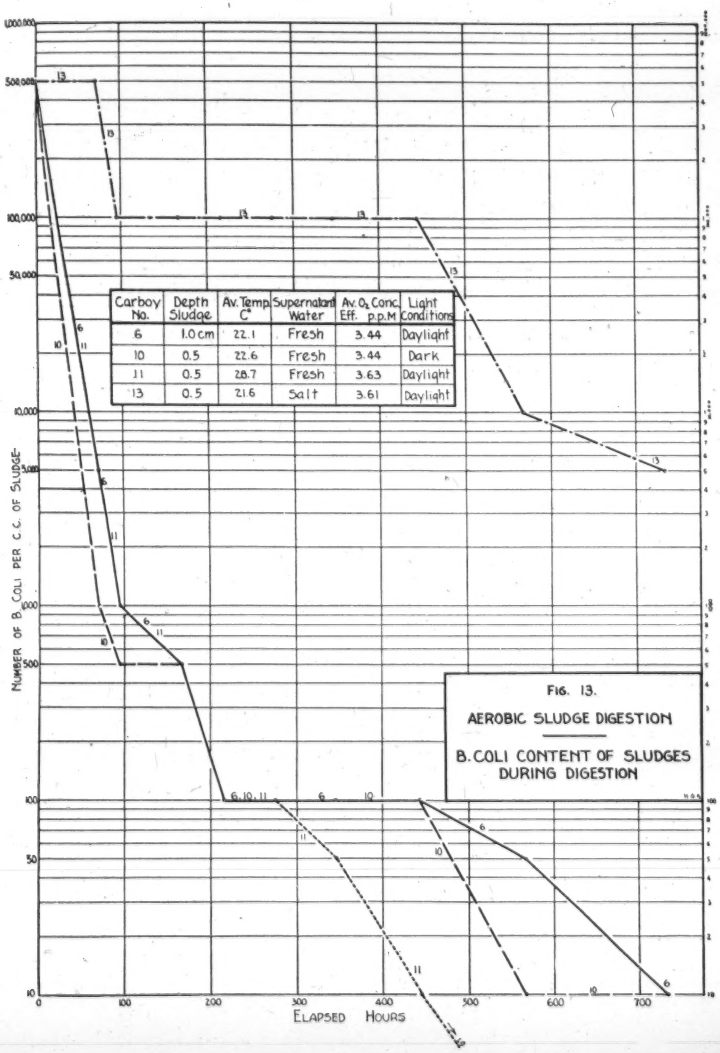

Carboy No. | Depth Sludge | Av. Temp C° | Supernatant Water | Av. O2 Conc. Eff. p.p.M | Light Conditions
6 | 1.0 cm | 22.1 | Fresh | 3.44 | Daylight
10 | 0.5 | 22.6 | Fresh | 3.44 | Dark
11 | 0.5 | 28.7 | Fresh | 3.63 | Daylight
13 | 0.5 | 21.6 | Salt | 3.61 | Daylight
FIG. 13.
AEROBIC SLUDGE DIGESTION
B. COLI CONTENT OF SLUDGES DURING DIGESTION
NUMBER OF B. COLI PER C.C. OF SLUDGE
ELAPSED HOURS
0
100
200
300
400
500
600
700
10
50
100
500
1,000
5,000
10,000
50,000
100,000
500,000
1,000,000

FIG. 13.

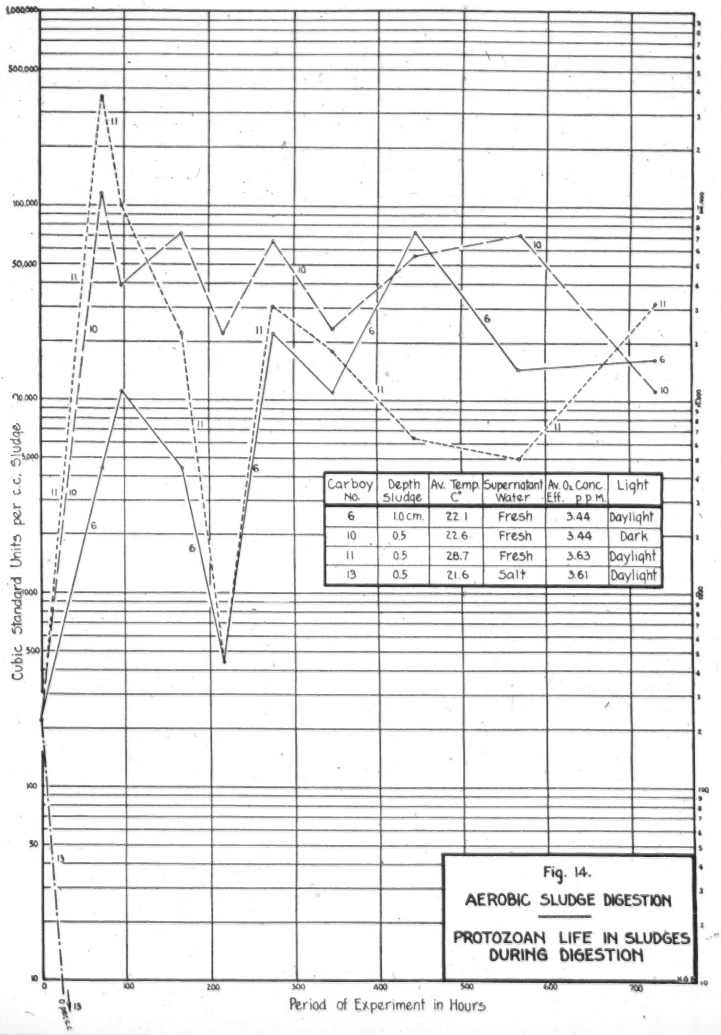

Cubic Standard Units per c.c. Sludge
Period of Experiment in Hours
Carboy No. | Depth Sludge | Av. Temp C° | Supernatant Water | Av. O2 Conc. Eff. p.p.m. | Light
6 | 1.0 cm. | 22.1 | Fresh | 3.44 | Daylight
10 | 0.5 | 22.6 | Fresh | 3.44 | Dark
11 | 0.5 | 28.7 | Fresh | 3.63 | Daylight
13 | 0.5 | 21.6 | Salt | 3.61 | Daylight
Fig. 14.
AEROBIC SLUDGE DIGESTION
PROTOZOAN LIFE IN SLUDGES DURING DIGESTION

FIG. 14.

Conclusions

From the various phases of this study the following recapitulation is made:

Total Oxygen Demand

1. The time required for essentially complete stabilization of a sludge film of 0.089 cm. thickness at 21.2° C. was about 36 days.

2. The total oxygen demand of the sludge was 540,000 p.p.m. on the basis of total dry solids, or 635,000 p.p.m. on the basis of dry organic solids content.

3. The average rate of oxygen demand of the 0.089 cm. sludge layer over the total period was 17.6 mg. per day per gram of organic solids, or 632 mg. of O_2 per day per square meter of surface area. The maximum rates observed were 66 mg. and 2,360 mg. respectively.

4. The oxygen demand curve departs from the characteristic B.O.D. curve of liquid wastes in having a steeper slope after the primary and secondary stages. This is attributable to the continuous conversion of solids into assimilable food products.

Effect of O_2 Concentration in Supernatant Water

5. There appears to be no correlation between the rate of oxygen demand and the amount of available dissolved oxygen in the supernatant water.

6. The oxidation processes will proceed at their normal rates provided there is any residual oxygen in the water.

7. A period of septicity of a sludge deposit has no appreciable effect upon the resumption of aerobic activity when oxygen is again available.

Effect of Depth of Sludge Deposit

8. The rate of oxygen demand is not a direct function of the depth of sludge deposit, the increase in rate being smaller than the increase in depth.

9. The relationship between rate of demand and depth of deposit is expressed by an exponential formula of the general type: $y = ax^b$. For the particular sludge under study, under conditions of fresh water, at a temperature of 22° C., and between the limits of 0 and 4.0 cm. depth, the relationship was approximately:

$$Y = 2700\ X^{0.485}$$

where X is the sludge depth in centimeters and Y is the rate of O_2 demand in milligrams per day per square meter of sludge surface.

10. The critical depth for stability of a deposit of fresh sludge is about one centimeter. Oxygen does not appear to diffuse to greater depths, with the result that anaerobic action goes on in the lower layers simultaneously with the aerobic action at the surface. The evolved gases exert a disrupting action on the sludge deposit.

11. Aerobic sludge decomposition is primarily a surface phenomenon. The increased O_2 demand of greater depths is probably due to the effect of unstable gases of anaerobic origin and to the increased area of new sludge surfaces brought into contact with the water by their stirring action.

Effect of Light

12. Sunlight appears to exercise no influence upon the metabolism of the organisms responsible for the aerobic decomposition of sludge.

13. Under natural stream conditions, the influence of light would be limited to indirect effects produced by the oxygen liberated by algal forms of aquatic life.

Effect of Temperature

14. Within the thermal range of natural streams, an increase in temperature is accompanied by a proportionately greater increase in the rate of aerobic decomposition of organic deposits. This relationship is believed to be expressed with reasonable accuracy by the biochemical formula proposed by Phelps.

Effect of Salinity

15. In waters of high saline content the rate of oxygen absorption is appreciably lower than in fresh water.

16. At 22° C. sludge digesting under fresh water abstracted 1.8 times as much oxygen as a like sample under water containing 10,000 p.p.m. chlorides.

17. Within the limits of salinity of natural tidal waters, it appears that the rate of oxygen demand is practically an inverse straight-line function of the salinity of the water.

18. Long-time B.O.D. curves from parallel dilutions of fresh and sea-water confirmed results of the carboy experiments. The curves for sea-water failed to show the "secondary stage" which is characteristic of fresh water dilutions and which is usually ascribed to nitrification processes.

Bacterial and Protozoan Life

19. Light and salinity do not appear to affect the saturation population of bacteria in aerobic sludge, as indicated by the 20° C. gelatin count, although increased temperature produces greater numbers.

20. The agar counts at 37° C. showed no great variations in bacteria for different conditions of light, sludge depth and salinity, but a rise in population with increased temperatures. Under all conditions there was a marked decrease with time.

21. The *B. Coli* content decreased with great rapidity in all the fresh water samples. In the sludge underlying salt water, the longevity of the organisms was very much greater.

22. Under fresh water conditions the protozoan content of the sludges increased very rapidly and showed no choice as to light or temperature. Antagonisms in the battle for food caused a rapid succession of species, from the smaller to the larger forms. In the salt water sample all protozoan life disappeared within the first 24 hours, and did not reappear at any later time. Their absence may explain the lower B.O.D. rates observed under saline conditions. No algae or other forms of vegetable life were observed in any of the samples, due, doubtless, to the continuous-flow principle of operation.

Deficiencies of Experiment

It is recognized that the short period of the experiment, as compared with the very long periods required for complete stabilization of sludge deposits of appreciable depth, fails to establish many factors with finality and yield absolute results. The primary value of the work probably lies in the trends and comparisons which are indicated. These studies are being continued and expanded with the expectation that more definite and generally applicable measures of the decomposition of river deposits may be developed.

Acknowledgment

The work reported in this paper was done largely during the year 1925–26 in the Harvard Graduate School of Engineering while the author was a research fellow of the Rockefeller Foundation. The splendid assistance of these two institutions is gratefully acknowledged. Particular credit and thanks are due Professor Gordon M. Fair, who directed the studies, and Professor Melville C. Whipple, who rendered valuable aid and guidance throughout the experiment.

References

1. Willem Rudolfs, *This Journal*, **4**, 315 (1932).
2. Report of Committee on Charles River Dam, 279 (1903).
3. E. J. Theriault and P. D. McNamee, *Public Health Reports*, **46**, 1301 (1931).
4. British Royal Commission on Sewage Disposal, 8th Report, **2**, 150 (1913).
5. E. J. Theriault, *Transactions, American Society Civil Eng'rs*, **89**, 1341–1350 (1926).
6. E. J. Theriault, P. D. McNamee and C. T. Butterfield, *Pub. Health Repts.*, **46**, 1084–1116 (1931).
7. H. Heukelekian, *Pub. Health Reports*, **44**, 1544–1555 (1929).
8. C. T. Butterfield, W. C. Purdy and E. J. Theriault, *Pub. Health Repts.*, **46**, 393–426 (1931).
9. W. C. Purdy, *Pub. Health Repts.*, **52**, 945–978 (1937).
10. Earle B. Phelps, *U. S. Geol. Survey Water Supply Paper*, **229**, 74 (1909).
11. H. W. Streeter and E. B. Phelps, *Pub. Health Bulletin*, **146** (1925).
12. H. W. Streeter, *Transactions, American Society Civil Eng'rs*, **89**, 1351–1364 (1926).
13. J. K. Hoskins, *Transactions, American Society Civil Eng'rs*, **89**, 1365–1377 (1926).
14. E. J. Theriault, *Public Health Bulletin*, **173** (1927).
15. G. M. Fair, *This Journal*, **8**, 430 (1936).
16. H. A. Thomas, *This Journal*, **9**, 425 (1937).
17. Report Metropolitan Sewage Commission of New York, 631–632 (1914).
18. M. Hotchkiss, *Jour. Bact.*, **8**, 141–162 (1923).
19. Report Engineering Board of Review, Sanitary District of Chicago, Part III, Appendix 1 (Eddy Report), Sewage Disposal (1925).

THE POLLUTION AND NATURAL PURIFICATION OF ILLINOIS RIVER BELOW PEORIA

By W. H. Wisely and Clarence W. Klassen

Asst. Sanitary Engineer and Chief Sanitary Engineer, Illinois Dept. of Public Health, Springfield, Ill.

Preliminary Statement

In past years, the pollution of the Illinois River by The Sanitary District of Chicago has been widely discussed, but little attention has been given to other sources of pollution along its course. Since 1919, a gradual but steady progress has been made by The Sanitary District of Chicago to provide facilities for the collection and treatment of sewage and industrial wastes originating within its boundaries. In 1937, the condition of the Illinois River above Peoria had improved so greatly that the time has come to consider the pollution discharged at various points downstream from Lockport, the terminus of the Main Channel of The Sanitary District of Chicago, including untreated sewage from municipalities and wastes from a wide variety of industrial interests scattered along the river shores from Joliet to Grafton.

This report covers the effects on the Illinois River of pollution originating in the metropolitan area of Peoria and Pekin. The combined human population of these two cities is about 130,000 persons. In addition, there must be considered the industrial waste discharged to the Illinois River in the area, which created in 1936 a pollution load equivalent to the raw sewage discharged by more than one million people. The Greater Peoria Sanitary District has provided excellent facilities for treating the human sewage originating in Peoria and its suburbs, with a slight amount of industrial wastes. This treatment handles the equivalent of 115,000 persons with what might be called a 90 per cent reduction, leaving a residual equivalent pollution of approximately 12,000 people. From a metropolitan area of this size, a pollution load equivalent to over a million people is very surprising, but our survey has shown that it is due largely to the increased activity in the distilling industry, following the repeal of prohibition in 1933. As a result, oxygen conditions have become critical in the Illinois River below Peoria. On the other hand, through the efforts of The Sanitary District of Chicago, satisfactory conditions now exist directly above Peoria in the Illinois River and for many miles upstream.

The extremely low river flows prevailing during the summer of 1936 presented an excellent opportunity to study the self-purification of the Illinois River below Peoria. The data upon which this report is based were collected during July and August, 1936, through the combined efforts of the Illinois State Sanitary Water Board, the State Department of Conservation, The Sanitary District of Chicago and The Greater Peoria Sanitary District.

The original object of the study was to decide on a pollutional limit upon which to base requirements for the degree of treatment necessary by the various industries and municipalities involved. However, the time

spent in studying the river was relatively short. Therefore, in view of the very important changes which will occur in the river flow after 1938, no extended analysis has been made of the effect on the future, but a brief statement is given to indicate the need of taking steps to reduce pollution. Among the more important changes which will materially affect the Illinois River after 1938 are:

1st. The reduction in the average annual diversion from Lake Michigan, from 5,000 c.f.s. to 1,500 c.f.s. on December 31, 1938, in accordance with the decree of the United States Supreme Court of April 21, 1930;

2nd. The further reduction in the pollution originating in The Sanitary District of Chicago upon the completion of the new treatment works at Stickney now under construction;

3rd. The effect on the hydraulic characteristics of the Illinois River below Peoria of the construction of the new lock and dam by the War Department at Mile 157.7, the relocation of the La Grange Lock and Dam, and the dredging of the 9-foot navigable channel.

Regardless, however, of the changes which may occur, the study of the self-purification capacity of the Illinois River between Peoria and Beardstown in July and August of 1936 will be of value for guidance in the development of the pollution abatement policy for the lower river.

In considering a report of this kind, one should keep in mind that computations of this nature should be considered largely as estimates and not as absolute values. Two months is a very short time on which to determine absolute values. However, the data and computations are believed to be adequately representative and sufficiently accurate to justify our conclusions.

General Information

Description of River Stretch Studied

This study is based on that portion of the river between the Peoria Upper Wagon Bridge (Mile 166.1) and the Beardstown Wagon Bridge (Mile 88.6). Fig. 1 shows in detail the stretch studied.

The upper station Mile (166.1) is located at the "Narrows" in Peoria Lake. From this point down to the Peoria Lower Wagon Bridge (Mile 162.3) the river passes through the lower part of Peoria Lake, the section being wide and shallow. Below the foot of the lake to Beardstown the main channel of the river is reasonably uniform in slope and section. The only appreciably sharp bends occur at about Miles 160.0 and 151.0, the latter point being just below Pekin.

Both river banks below Peoria Lake are bordered by low ground, much of which has been drained for cultivation, although a number of bays, backwater areas, lakes and sloughs still remain. Most of these bodies of water are located between Kingston Mines (Mile 145.5) and Havana (Mile 119.6) but Pekin Lake just above Pekin, and Muscooten Bay, just above Beardstown are also of material size. The influence of the ponded areas

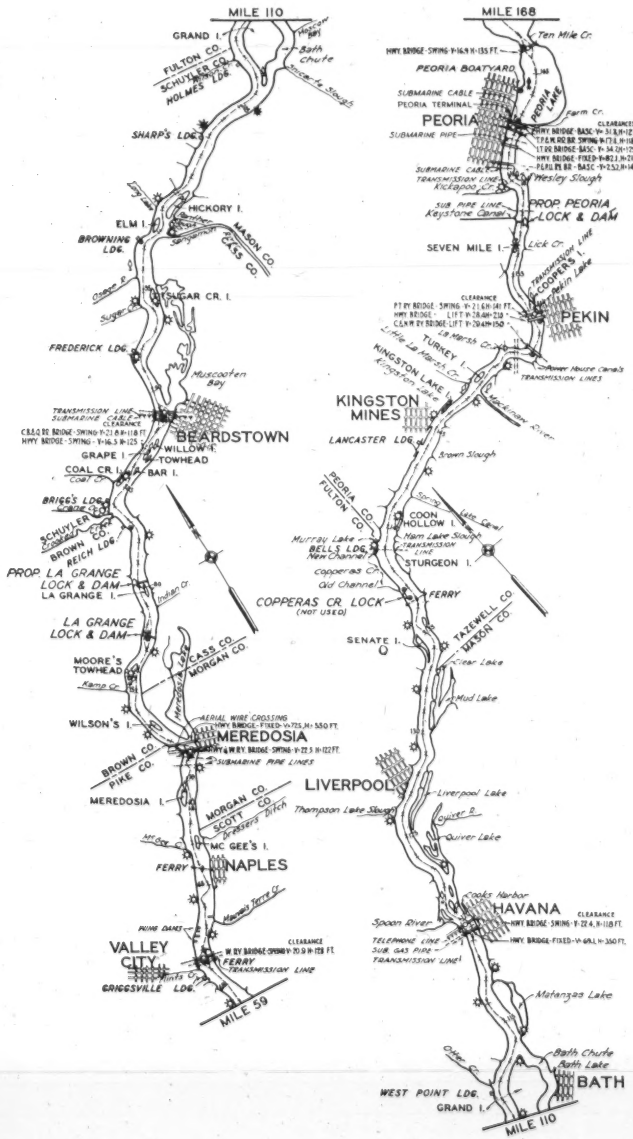

MILE 110
GRAND I.
FULTON CO.
SCHUYLER CO.
HOLMES LDG.
Bath Chute
Sugar Creek Slough
SHARP'S LDG.
HICKORY I.
ELM I.
BROWNING LDG.
MASON CO.
CASS CO.
SUGAR CR. I.
FREDERICK LDG.
Muscooten Bay
TRANSMISSION LINE
SUBMARINE CABLE
CLEARANCE
C.B.Q. RR. BRIDGE - SWING - Y-21.8 H-118 FT.
HWY. BRIDGE - SWING - Y-116.5 H-125
BEARDSTOWN
WILLOW I.
TOWHEAD
GRAPE I.
COAL CR. I.
BAR I.
BRIGG'S LDG.
SCHUYLER CO.
BROWN CO.
REICH LDG.
PROP. LA GRANGE LOCK & DAM
LA GRANGE I.
LA GRANGE LOCK & DAM
CASS CO.
MORGAN CO.
MOORE'S TOWHEAD
WILSON'S I.
AERIAL WIRE CROSSING
HWY. BRIDGE - FIXED - V-175, H-550 FT.
MEREDOSIA
ATSF & W. RY. BRIDGE - SWING - Y-21.5 H-122 FT.
SUBMARINE PIPE LINES
BROWN CO.
PIKE CO.
MEREDOSIA I.
MORGAN CO.
SCOTT CO.
MC GEE'S I.
FERRY
NAPLES
PUMP DAMS
CLEARANCE
W. RY. BRIDGE - OPENING - Y-70.9 H-172 FT.
FERRY
TRANSMISSION LINE
VALLEY CITY
GRIGGSVILLE LDG.
MILE 59
MILE 168
Ten Mile Cr.
HWY. BRIDGE - SWING - Y-116.9 H-135 FT.
PEORIA BOATYARD
SUBMARINE CABLE
PEORIA TERMINAL
PEORIA
PEORIA LAKE
Farm Cr.
SUBMARINE PIPE
CLEARANCES
HWY. BRIDGE - BASC. - Y- 31.8, H-125 FT.
T.P.& W. RR. BR. - SWING - Y-73.8, H-118 -
I.T.W. BRIDGE - BASC. - Y- 34.2, H-175 -
HWY. BRIDGE - FIXED - Y-80.2, H-210 -
P.R.I. RY. BR. - BASC. - Y-25.2, H-140 -
SUBMARINE CABLE
TRANSMISSION LINE
Wesley Slough
SUB. PIPE LINE
Keystone Canal
PROP. PEORIA LOCK & DAM
SEVEN MILE I.
Lick Cr.
TRANSMISSION LINE
COOPER'S I.
Main Lake
CLEARANCE
P.T. RY. BRIDGE - SWING - Y- 21.6, H-141 FT.
HWY. BRIDGE - LIFT Y-28.6, H-218 -
C.& N.W. RY. BRIDGE - LIFT Y-29.6, H-150 -
PEKIN
La Marsh Cr.
TURKEY I.
Little La Marsh Ch.
KINGSTON LAKE
Kingston Lake
Mineral House Canal
TRANSMISSION LINES
KINGSTON MINES
West Indian River
LANCASTER LDG.
Brown Slough
PEORIA
FULTON CO.
Spring Lake Canal
COON HOLLOW I.
Murray Lake
Ham Lake Slough
BELL'S LDG.
TRANSMISSION LINE
New Channel
STURGEON I.
Copperas Cr.
Old Channel
FERRY
COPPERAS CR. LOCK
(NOT USED)
TAZEWELL CO.
MASON CO.
SENATE I.
Clear Lake
Mud Lake
LIVERPOOL
Liverpool Lake
Thompson Lake Slough
Quiver R.
Quiver Lake
Cooks Harbor
Spoon River
HAVANA
CLEARANCE
HWY. BRIDGE - SWING - Y-22.4, H-118 FT.
TELEPHONE LINE
SUB. GAS PIPE
TRANSMISSION LINE
HWY. BRIDGE - FIXED - Y- 69.2, H-350 FT.
Matanzas Lake
Bath Chute
Bath Lake
BATH
WEST POINT LDG.
GRAND I.
MILE 110

FIG. 1.

on the condition of the river was not studied, it being considered probable that their greatest effect will be exerted during higher river stages.

The principal tributaries entering Illinois River in the reach surveyed are as follows:

Tributary	Drainage Area (sq. mi.)	Enters Illinois River (Mile)
Mackinaw River	1174	147.7
Spoon River	1812	120.6
Sangamon River	5332	99.0

Sources of Pollution

The principal pollution in the stretch of river studied comprises industrial wastes originating at Peoria and Pekin. Untreated sewage discharge from the cities located in the river stretch is of minor importance in comparison.

Detailed studies of the major sources of industrial pollution, made jointly by the State Sanitary Water Board and the Peoria Sanitary District in 1936, included the determination of strength and volume of wastes discharged to the river. It is, therefore, possible to estimate with acceptable accuracy, the actual load imposed upon the river during July and August, 1936.

The pollution loads placed upon the river at Peoria and Pekin during the period of the survey are herewith itemized:

PEORIA POLLUTION

Source	Nature of Wastes	Pounds Per Day 20-Day, 20° B.O.D.*	Population Equivalent of Wastes †
Commercial Solvents Corp.	Distillery	66,250	265,000
Hiram Walker & Sons, Inc.	Distillery	31,750	127,000
Century Distilling Co.	Distillery	1,500	6,000
Bemis Bros. Bag Co.	Paper Mfg.	750	3,000
Barrett Company	Roofing Felt Mfg.	500	2,000
Gipps Brewing Co.	Brewery	750	3,000
Peoria Sanitary District	Treated sewage	2,500	10,000
	Totals	104,000	416,000

PEKIN POLLUTION

Source	Nature of Wastes	Pounds Per Day 20-Day, 20° B.O.D.*	Population Equivalent of Wastes †
Standard Brands Inc.	Yeast	25,000	100,000
American Distilling Co.	Distillery	50,000	200,000
Corn Products Refining Co.	Corn Products	3,750	15,000
Quaker Oats Company	Paper Mfg.	500	2,000
City of Pekin	Raw sewage	4,000	16,000
	Totals	83,250	333,000

* Of wastes discharged during period of July 18 to August 31.
† Based on 0.25 pounds 20-day B.O.D. per capita per day.

In addition to the above industrial wastes at Peoria, the National Distillers Products Corp. (Penn-Maryland plant) and Terre Haute Paper Company plants, which were not operating during the survey, produced wastes having a combined 20-day, 20° B.O.D. of 79,000 pounds per day (316,000 population equivalent) when operating. Upon resumption of operation, the load imposed by the Penn-Maryland plant will be reduced because of provision for by-product recovery. These industries must be considered with those tabulated in any river computations pertaining to conditions during maximum pollution.

The pollution contributed by Peoria sources during the sampling period are concentrated between Mile 159.8 and Mile 161.5. The Pekin industrial load enters the river at about Mile 151.4.

Other pollution contributed in the stretch is of minor consequence, including the sewage load at Havana which is estimated to have a 20-day, 20° B.O.D. of only 700 pounds per day.

Sampling Stations

Analytical data on the quality of the river water at five sampling stations are available for this report. The stations were located as follows: (See Figure 1):

Station	Miles Above Mouth of River	Remarks
Peoria Upper Bridge	166.1	Above pollution
Pekin Highway Bridge	152.9	Below Peoria pollution
Kingston Mines	145.5	Below all pollution
Havana	119.6	.....
Beardstown City Bridge	88.6	.....

The extreme upper and lower stations, Peoria Upper Bridge and Beardstown respectively, have been maintained in continuous operation by The Sanitary District of Chicago for some years and all data pertaining to these stations were obtained from that source.

The stations at Pekin, Kingston Mines and Havana were maintained by the State Sanitary Water Board only for the period of this study. A central field laboratory was located at Havana to handle samples collected at these three points.

Hydrometric Studies

The base data for the computations made in the study includes (1) the rates of discharge of the river proper at each sampling station (2) the rates of discharge of each principal tributary near its mouth (3) the mean times of flow between sampling stations and (4) the mean surface areas of the river between stations. These data apply only to the period of July 18 to August 31.

All of the information from which the above river data were determined was obtained from the Peoria District office of the U. S. Engineer Corps.

In the following discussion, it will be noted that the backwater areas, flanking lakes, borrow reaches and sloughs along the river are not considered. In support of this conclusion, it is offered that while these influences would probably be material in computations involving yearly

average data, their effects will be at a minimum during low river stages. As this study is over an extreme low discharge period, no field data were collected which would make detailed consideration of the "still-water" areas possible.

Rates of Discharge—Illinois River

United States Engineer Corps gauging stations are located at Havana and Pekin and discharge measurements have been taken at these points from one to six times monthly during the past seven years. As the discharge measurements at low stages at the Havana station appeared to be considerably more influenced by changes in water surface slope than at Pekin, the mean river discharge during the period of July 18 to August 31 was determined at Pekin as a basis for the discharge data used in this report. The mean discharges at other sampling stations were estimated by correcting the discharge at Pekin according to the drainage area tributary at each station, a run-off factor based on the measured run-off to the nearest tributary being used.

The unusually low river stages prevailing during the sampling period made the development of a dependable low stage rating curve somewhat difficult. A curve, based on arithmetical averages of the measured discharges at low stages (between 434.61 and 436.30 M.S.L., 1929 adjustment) during 1934 and 1936, was finally adopted. The curve was extended slightly for values below 434.61 M.S.L.

Values representing the mean river discharge at each sampling station during July and August, 1936 are contained in Table 1. Rates of discharge were remarkably consistent during this period.

TABLE I.—*Illinois River Survey—July and August, 1936*
Summary of Hydrometric Data

Stretch of River		Length of Prism (Miles)	Average Discharge (c.f.s.)	Average Velocity (Miles per Hour)	Average Hours of Flow	Hours from Upper Peoria Bridge	Surface Area (1000 Sq. Ft.)
From	To						
Peoria Upper Bridge (Mile 166.1)	Pekin Highway Br. (Mile 152.9)	13.2	8530	0.73	17.3	17.3	127,150
Pekin Highway Bridge (Mile 152.9)	Kingston Mines (Mile 145.5)	7.4	8595	0.93	8.0	25.3	26,740
Kingston Mines (Mile 145.5)	Havana (Mile 119.6)	25.9	8685	1.07	24.2	49.5	84,610
Havana (Mile 119.6)	Beardstown Highway Br. (Mile 88.6)	31.0	8925	1.11	27.9	77.4	100,520

Rates of Discharge—Tributaries

A tabulation furnished by the U. S. Engineer office at Peoria, showing low water discharges of the principal tributaries of Illinois River gives the following discharges for those streams discharging in the reach covered by this survey:

Tributary	Low Water Discharge (C.F.S.)
Mackinaw River	51
Spoon River	63
Sangamon River	336
Total	450

These figures were checked by data furnished by the State Water Survey for the Mackinaw and Spoon Rivers and are considered representative of conditions existing during the period July 18 to August 31, 1936.

The total flow of the tributaries comprises only about 5 per cent of the total discharge of the river as determined at Pekin, thus their influence on the River was slight during this period. However, inflow corrections for tributaries are made in the computations included in the latter part of this report, the analytical data being taken from U. S. P. H. S. *Bulletin* 171 in which information covering July and August, 1922, is included. Available personnel and facilities did not permit sampling of tributaries at this time.

Time of Flow

The times of flow through the individual prisms included between successive sampling stations were obtained from mean velocities determined at one-mile intervals from Beardstown (Mile 88.6) to Peoria Upper Bridge (Mile 166.1).

The cross-sectional areas at each mile interval were developed from soundings (referred to a defined Low Water Level) taken by the U. S. Engineer Corps and plotted to a scale of 1 in. = 200 ft. The mean river depth determined by averaging the soundings, multiplied by the surface width, gave the cross-sectional area at the defined Low Water Stage. The mean discharge during the period July 18 to August 31 was only slightly above that at the defined Low Water Level, but the cross-sectional area correction, found to average about 6 per cent, was added to give the areas used. In determining cross-sectional area, the sloughs, backwater areas and borrow reaches were not considered.

The discharge (assumed to vary uniformly through the prism) divided by the corrected cross-sectional area gave the velocity for each mile, from which the mean velocity and time of flow through each prism was computed.

The above method is considered to be sufficiently accurate for all prisms except that length of the river through Peoria Lake (Mile 166.1 to Mile 162.3). There is no doubt that the actual mean velocity through this stretch is greater than the value of 0.23 miles per hour resulting from the cross sectional areas as found above. Float observations through Peoria Lake by The Sanitary District of Chicago in 1902 showed the velocity to be about 0.5 miles per hour during low stages, which figure will be used herein in lieu of a definite correction for the computed value.

Table I includes the mean velocities and times of flow prevailing between sampling stations during the study.

Surface Areas

Measurements of the stream surface width were available from the same topographic maps used in determining cross-sectional areas for the velocity calculations. The width was scaled at six to ten points per mile at the defined Low Water Level and averaged for the mile. The difference between the surface areas at the defined Low Water Level and the actual water surface elevation was too small to warrant a correction and again the backwater-areas, lakes, sloughs and borrow reaches were disregarded.

From these average widths the water surface areas as estimated for each prism are shown in Table 1.

Field and Laboratory Studies

Operation of Sampling Stations

Peoria Upper Bridge (operated by Sanitary District of Chicago).—Samples were taken at this station from 4:00 P.M. to 7:00 A.M. daily except on Saturdays. B.O.D. samples were collected hourly and made into 4-hour composites and taken to the Peoria branch laboratory of The Sanitary District of Chicago. Temperature observations and samples for dissolved oxygen were taken hourly, the Rideal-Stewart modification being used in the dissolved oxygen determination.

Pekin, Kingston Mines and Havana.—These stations were in operation 24 hours per day except for brief intervals when adverse weather conditions made it impossible to take samples. No data are available for the Pekin station for the period of August 3 to 9 inclusive, due to a temporary shortage of samplers. The personnel engaged in collecting the samples comprised mostly men trained in sanitary engineering with a few picked employees of the State Department of Conservation. The central laboratory at Havana was in charge of a trained sanitary chemist.

B.O.D. samples collected during the first week of the sampling period consisted of samples taken every 2 hours throughout the entire day. The remainder of the B.O.D. samples were 4-hour composites made up of portions taken each hour. All samples were iced during collection and delivery to the central field laboratory at Havana.

Dissolved oxygen samples were collected hourly throughout the entire day, standard one-bottle samplers being used. Samples were treated to the point of titration in the field, stored in metal containers and taken to the Havana laboratory for titration. The Rideal-Stewart modification of the Winkler method was used.

Air and river temperatures were taken hourly.

Individual cross-section studies at each sampling station were made in order to determine any consistent variation in quality of water across the section, which should be considered in the definite location of a sampling point. At the Kingston Mines and Havana stations this factor was found to be of small importance but at Pekin it becomes of material consequence.

Four cross-sectional surveys of dissolved oxygen variation across the main channel at Pekin showed a definite range from about 1 p.p.m. near the west bank to nearly 5 p.p.m. at a point 300 feet distant in the channel.

It is evident from this that the Peoria pollution, introduced from the west bank, is not completely distributed across the full width of the river at this station.

As the dissolved oxygen study was not accompanied by velocity determinations across the stream channel, it is unlikely that sufficient information was available to permit the proper location of a sampling point. The samples collected at the Pekin station are, therefore, subject to considerable question and the data concerning this station are used sparingly in later computations.

Beardstown City Bridge (Station operated by The Sanitary District of Chicago).—Samples taken from 7:00 A.M. to 12:00 midnight daily except Sundays. Four-hour composites were taken for B.O.D. determinations, the samples being handled at the Beardstown branch laboratory of The Sanitary District of Chicago. Observations of river temperature were made hourly as were dissolved oxygen determinations.

Laboratory Procedure

The procedure followed in The Sanitary District of Chicago branch laboratories at Peoria and Beardstown is standard in all respects.

An important deviation from standard B.O.D. determination was practiced at the State field laboratory at Havana in that lack of 20° incubator capacity made it necessary to use a large capacity steel tank through which river water was circulated by a pump. During incubation, therefore, samples were subject to the same temperature variations as the river and incubation tank temperatures were taken hourly. The variation in temperature was appreciable, the maximum daily being 5° C. (July 18–27) and the maximum 5-day variation, 10° C. (August 28–31). The method employed in converting the 5-day B.O.D. results thus obtained at variable temperatures to 20-day B.O.D. (total first stage) at 20° is described later.

An attempt was made to ascertain the influence of incubation at variable temperatures as compared to incubation at 20° but the results obtained were not sufficiently conclusive to justify any correction of the data as assembled for use herein.

Except for the first 10 days of the survey, the dilution water used for B.O.D. determination was aged, seeded distilled water containing 300 p.p.m. sodium bicarbonate. Duplicate dilutions were generally incubated of all samples, concentrations of 20 per cent and 40 per cent or 25 per cent and 50 per cent being usually satisfactory.

Analytical Results

The temperature, dissolved oxygen and biochemical oxygen demand results at each station for the period July 18 to August 31 are included in Table II, and the average results for the period are shown in Table III.

Dissolved Oxygen.—Because the collection of samples at Peoria Upper Bridge was carried on from 4:00 P.M. to 7:00 A.M. daily, at Beardstown from 7:00 A.M. to 12:00 midnight and at all other stations throughout the

TABLE II.—*Illinois River Survey—July and August 1936.*
Summary of Analytical Results
State Sanitary Water Board & State Dept. Public Health

Date	River Temperature (° C.)					Dissolved Oxygen (P.p.m.)					20° C., 5 Day B.O.D. (P.p.m.)				
	Peoria	Pekin	K. Mines	Havana	Beardstown	Peoria	Pekin	K. Mines	Havana	Beardstown	Peoria	Pekin	K. Mines	Havana	Beardstown
July															
18	—	29.5	28.4	30.4	29.5	—	1.6	2.3	1.4	3.5	—	6.2	6.4	6.0	5.1
19	25.9	28.1	27.2	29.6	—	5.2	1.6	2.0	1.5	—	4.1	5.6	5.0	3.9	—
20	25.5	26.6	25.8	28.2	27.5	5.2	1.4	2.6	1.6	3.5	3.8	6.8	5.9	4.2	3.9
21	24.6	25.7	25.2	27.2	26.8	5.6	2.9	3.0	2.2	4.5	4.5	8.1	5.6	6.1	1.5
22	24.4	25.7	25.3	27.0	27.4	5.1	2.3	3.1	2.5	4.9	5.2	8.1	5.8	6.9	2.8
23	25.5	25.9	26.3	27.4	28.0	5.8	1.6	2.9	2.9	5.5	5.4	8.3	7.2	5.7	1.3
24	25.0	25.9	25.8	27.2	27.7	6.4	2.0	2.7	2.7	5.6	5.3	9.0	8.2	6.0	1.4
25	—	26.4	25.2	27.1	27.4	—	1.9	1.4	2.3	4.7	—	8.5	7.0	4.7	1.5
26	25.5	27.4	26.9	28.0	—	6.1	2.0	2.3	1.5	—	4.3	7.7	4.5	6.1	—
27	26.8	27.6	27.4	28.1	28.8	7.2	3.3	3.1	2.4	4.3	5.8	7.3	7.3	2.4	3.6
28	26.9	28.6	—	28.7	28.9	7.2	3.0	—	2.1	4.3	6.4	7.3	6.9	2.4	—
29	25.2	25.8	26.3	27.8	27.5	6.4	2.9	3.6	2.4	4.7	5.5	10.7	8.0	5.2	2.2
30	23.7	24.5	24.9	26.5	26.5	6.7	2.8	3.7	3.0	5.0	4.6	10.7	7.4	5.4	3.8
31	23.9	24.4	24.6	26.0	26.0	6.8	3.0	3.7	2.8	5.3	4.9	9.4	5.6	5.3	4.1
August															
1	—	24.9	24.4	25.8	25.6	—	2.6	3.5	2.6	5.1	—	7.8	5.3	2.7	4.7
2	24.7	25.6	24.9	26.6	—	6.4	3.4	3.9	2.4	—	5.1	8.0	4.7	3.9	—
3	25.4	—	—	26.8	27.1	7.6	—	—	2.5	4.7	5.4	—	—	3.4	4.4
4	24.8	—	25.4	26.7	26.8	7.2	—	2.6	1.7	4.8	6.0	—	8.9	5.0	4.5
5	22.9	—	23.6	25.1	24.0	6.1	—	1.9	1.1	3.1	5.0	—	8.1	4.9	3.9
6	23.4	—	24.0	25.1	25.1	5.9	—	1.8	1.2	2.7	4.5	—	6.6	5.3	4.4
7	24.8	—	24.7	25.5	25.4	6.5	—	2.2	1.4	3.5	3.5	—	7.5	3.8	3.6
8	—	—	24.8	25.8	24.7	—	—	2.5	1.7	3.9	—	—	8.3	4.4	4.4
9	26.1	—	25.3	26.2	—	7.0	—	1.5	1.3	—	4.6	—	9.5	4.6	—
10	25.5	27.3	25.8	27.4	25.8	7.9	4.0	4.2	2.7	4.8	4.8	6.2	7.3	3.6	4.6
11	25.2	26.2	26.0	27.2	25.9	7.8	2.9	2.8	2.2	4.9	5.0	8.6	7.3	5.8	4.2
12	25.5	26.9	26.4	27.7	27.3	7.3	3.0	2.7	1.8	4.0	4.4	10.4	8.2	6.5	3.6
13	26.5	27.7	27.3	28.3	28.2	7.6	2.1	3.0	2.0	4.1	5.5	10.7	7.6	6.0	4.3
14	26.4	27.1	27.1	28.1	27.9	6.5	1.4	2.4	2.0	4.1	6.3	9.7	8.4	5.1	3.6
15	—	27.5	27.4	28.4	28.9	—	1.7	1.7	1.8	4.1	—	10.3	8.7	5.3	3.8
16	27.9	27.3	27.4	26.8	—	7.7	1.2	1.5	1.6	—	6.1	10.3	9.3	6.4	—
17	26.7	28.0	—	28.9	28.3	7.2	3.0	—	1.9	3.6	5.5	—	—	7.5	4.2
18	26.3	29.0	28.1	29.0	29.2	6.0	2.8	2.7	1.9	3.4	5.7	9.4	9.8	6.2	3.8
19	26.9	28.2	28.6	29.3	29.4	7.0	2.4	2.9	1.9	3.6	6.6	10.6	8.3	5.7	3.9
20	27.2	26.9	27.2	28.2	28.9	7.0	2.4	2.0	1.9	3.5	5.4	9.8	9.0	7.0	5.1
21	27.3	29.5	28.4	29.0	29.7	6.2	2.6	1.9	1.4	3.3	3.5	8.6	10.0	8.4	4.5
22	—	28.9	28.8	29.6	29.7	—	0.9	1.6	1.6	1.9	—	9.8	9.7	7.2	5.0
23	26.7	28.8	28.8	29.9	—	7.8	1.9	2.0	1.8	—	5.1	9.7	9.0	7.5	—
24	28.0	29.2	29.0	30.1	29.9	6.7	2.4	2.3	1.7	2.3	4.8	9.8	8.1	7.5	3.5
25	27.6	28.1	29.7	30.0	30.0	6.3	2.0	1.7	1.6	2.9	7.0	9.7	9.3	6.0	4.9
26	26.8	27.8	28.5	29.9	30.0	6.9	1.5	1.8	1.7	3.9	5.8	11.6	9.3	5.7	3.3
27	26.7	26.6	27.4	29.2	28.7	6.3	1.4	1.5	1.6	3.6	4.2	12.4	9.7	5.7	4.2
28	25.4	26.8	26.6	28.0	29.0	6.3	1.1	1.2	1.6	3.2	5.3	14.2	10.2	7.2	4.7
29	—	25.0	25.0	26.5	26.1	—	1.2	1.3	1.6	3.4	—	12.6	10.5	7.5	5.7
30	22.1	23.8	24.1	25.5	—	6.9	2.6	2.2	1.7	—	6.3	10.3	8.8	6.4	—
31	22.3	23.5	23.3	25.0	24.7	6.2	3.2	2.7	1.6	3.5	4.5	9.1	6.5	4.3	5.5
Ave.	25.6	26.9	26.4	27.6	27.6	6.6	2.2	2.4	1.9	4.0	5.2	9.3	7.95	5.5	3.9

entire day, checks were made to determine whether comparable daily averages resulted at all stations.

A study of the hourly dissolved oxygen values obtained at Havana throughout the period of study disclosed that the average content for the 24-hour day was 1.95 p.p.m., the average from 4:00 P.M. to 7:00 A.M. was 1.99 p.p.m. and the average from 7:00 A.M. to 12:00 midnight was 2.04 p.p.m. If the hourly dissolved oxygen concentration is assumed to vary similarly at Peoria Upper Bridge (sampling time 4:00 P.M. to 7:00 A.M.) and at Beardstown (sampling time 7:00 A.M. to 12:00 midnight) the error from the 24 hour average will be only 2.1 per cent at Peoria and 4.6 per cent at Beardstown.

From the average dissolved oxygen contents at each station for the entire period of the survey, included in Table III, it will be noted that a

TABLE III.—*Illinois River Survey—July and August, 1936*
Summary of Base Data
(July 18 to August 31)

Sampling Point	Peoria Upper Bridge	Pekin Highway Bridge	Kingston Mines	Havana	Beardstown City Bridge
Miles above mouth	166.1	152.9	145.5	119.6	88.6
Flow (c.f.s.)	8500	8560	8630	8740	9110
Time of flow					
Hours below Mile 166.1	—	17.3	25.3	49.5	77.4
Days between stations	—	0.72	0.33	1.01	1.16
Average velocity (M.P.H.)	—	0.73	0.93	1.07	1.11
Temperature (Degrees C.)	25.6	26.9	26.4	27.6	27.0*
Dissolved oxygen (P.P.M.)	6.6	2.2†	2.4	1.9	4.0
20° B.O.D.—Total first stage (P.P.M.)	7.5	13.6†	11.4	8.0	5.8

* Corrected slightly to make comparable to 24 hour averages of other stations.
† Believed erroneous due to non-representative samples.

slight increase in dissolved oxygen is indicated to take place in the stretch from Pekin to Kingston Mines, which is contrary to expectation. It will be remembered that the Pekin results are believed to be subject to some question due to possible sampling errors.

Biochemical Oxygen Demand.

In selecting B.O.D. results for daily averages at Pekin, Kingston Mines and Havana, any determination involving a depletion after 5 days' incubation of less than 1.0 p.p.m. or a final titration of less than 0.5 p.p.m. was discarded. A tendency for the high dilutions (20 per cent and 25 per cent) to show lower demands than the lower dilutions (40 per cent and 50 per cent) caused some concern. Checks with various types of dilution water failed to establish this factor as cause of the divergence. The distilled water used for dilutions was also tested for the presence of copper (sometimes introduced during faulty operation of the still), which tests proved negative. Accordingly, the lower dilutions (40 per cent and 50 per cent) were taken in all cases except in the few instances when only one dilution was incubated

In converting the variable temperature, 5-day B.O.D. results at Pekin, Kingston Mines and Havana, to 20-day (total first stage) B.O.D. at 20°, the 5-day value at $T°$ was first converted to the total first stage B.O.D. at $T°$ by applying the factors included in U. S. P. H. S. *Bulletin* **173**, page 165. Factors for fractional values of T were obtained by interpolation. The total first stage demands at $T°$ were then converted to the total first stage demand at 20° by means of the temperature relation suggested by Theriault:

$$L_T = L_{20}(0.02T + 0.60),$$

where L_T = total first stage biochemical oxygen demand at $T°$ C. and L_{20} = total first stage demand at 20° C.

The values of T used were the average 5-day incubation temperatures for the individual samples.

To illustrate the above, the following example is given: Assume a 5-day B.O.D. of 6.3 p.p.m. determined at an average incubation temperature of 27° C. The total first stage demand at 27° is 6.3 divided by 0.796 (79.6 per cent of the total first stage demand being satisfied in 5 days at 27°) which equals 7.9 p.p.m. Then the total first stage demand at 20° C. is determined by dividing 7.9 by $(0.02T + 0.60) = 1.14$ which equals 6.95 p.p.m. The 5-day B.O.D. at 20° would be 6.95 divided by 1.46 = 4.75 p.p.m.

Results of seven 10-day oxygen demand observations on samples collected at Havana (incubated at variable temperatures and converted to 20° values) were tested by Fair's "log-difference" analysis (This JOURNAL, **8**, 430) and the deoxygenation coefficient (k_1) was determined to be 0.1012. This compares favorably with the normal biochemical value of $k_1 = 0.10$ at 20° C. and confirms the method and coefficients used in converting the variable temperature B.O.D. results to the 20° basis.

The average total first stage B.O.D. results converted to 20° of the 4-hourly composite samples collected at Kingston Mines and Havana from July 18 to August 31, are shown in the following tabulation:

Station	Total First Stage, 20° B.O.D.						
	4 A.M.	8	12 Noon	4 P.M.	8	12 Mid.	Ave.
Kingston Mines	11.4	11.0	11.9	11.5	11.5	11.2	11.4
Havana	8.2	8.0	8.0	8.2	8.0	7.8	8.0

The above table indicates that there is little appreciable variation in B.O.D. of the river throughout the day and, consequently, the results at Peoria and Beardstown, where shorter sampling periods were used, may properly be taken to represent average daily values.

The data collected did not include studies for the influence of transition from first- to second-stage oxidation in the portion of the river surveyed but this factor is not believed to be of consequence. A curve showing the course of oxidation in the river below Pekin, based on data collected from 1927 to 1930, is included in a study by Streeter (This JOURNAL, **7**, 272), which curve shows the transition to second stage to take place about 9

days below Pekin. The estimated time of flow from Pekin to Beardstown during July-August, 1936, was about 2.5 days, which, added to the 5-day incubation period, gives 7.5 days. This would indicate that interference by second-stage oxidation was not likely.

Analysis of Oxygen Conditions

Procedure

The oxygen content of a polluted stream is dependent upon several influences. Oxygen is taken from the water to satisfy the demand exerted by (1) the organic matter in suspension or in solution in the water, (2) sludge deposits at the stream bottom and (3) organic matter from sludge deposits lifted by the ebullition of gas and replaced in suspension in the water. On the other hand, oxygen will be added to the river water by (1) reaeration from the atmosphere, (2) photosynthesis (not considered in this report), (3) dilution from less polluted tributaries, and (4) aeration in the passage over dams or through gate openings at high velocities.

In this report, the greatest difficulty arose in properly evaluating the influence of the sludge deposits. Since the analytical data were taken only over the critical, low discharge period of July and August, it may logically be assumed that the actual sludge accumulations in the river are far greater than would be measured by the available analytical data. This assumption is based on the logical hypothesis that organic solids deposited during the preceding winter, when temperatures were unfavorable for oxidation, did not exert their greatest oxygen demand until the more favorable summer temperatures prevailed.

The following procedure, which is believed to approximate the influence of sludge deposits reasonably well, was adopted after considerable study:

1. The observed B.O.D. and D.O. results were corrected for the pollution or dilution entering the river in each stretch.
2. A "gross rate" of surface reaeration was determined by the "oxygen balance" method (used by the Eddy Committee) from which an initial rate of reaeration at zero D.O. saturation was established. From this initial rate, the total pounds of oxygen absorbed by surface reaeration in each stretch was estimated. (Note: At this point the D.O. and B.O.D. results at Mile 166.1 above Peoria were referred to Mile 162.0, which is just above the point of discharge of the Peoria pollution.)
3. The total amounts of oxygen utilized in each stretch were estimated by algebraic addition of the oxygen absorbed by reaeration and the change in dissolved oxygen in the stretch. The sum thus obtained can be taken as the total oxygen demand exerted (X_t) and, by subtracting the computed demand exerted in each stretch by organic matter in suspension in the river water, the remainder is considered to be demand exerted by all influences directly or indirectly due to the presence of sludge deposits.
4. Based on the total oxygen demands exerted, determined as above, the "composite" coefficient of deoxygenation (k_1) for each stretch was computed.

5. Using these values of k_1 and values of L_a (total initial B.O.D.) computed directly from X_t, the coefficients of reaeration (k_2) were determined and averaged by weighting according to the time of flow.

6. Applying the coefficients k_1 and k_2 as determined in (4) and (5) above, a computed "oxygen sag" curve was developed for comparison with the observed D.O. contents in the entire reach of river studied.

7. By determining a value for L_a that could be taken as representing conditions in the river with all sludge deposits absent, an oxygen sag curve was computed to show the estimated D.O. content under those conditions.

8. By further application of the coefficients determined above, the total pollution load which could be discharged at Peoria and Pekin without causing a reduction in river dissolved oxygen below a threshold of 4.0 p.p.m., was estimated.

Inflow Corrections

Table IV summarizes the corrections made in the observed average B.O.D. and D.O. results for the inflow of pollution and tributary streams. It will be noted that the influence of tributaries is minor.

TABLE IV.—*Illinois River Survey—July and August, 1936*
Inflow Corrections
(Figures expressed in thousands of pounds per day)

Station	Sources of Inflow	B.O.D. (River Temp.)					D.O.		
		Observed at Station	Amount Contributed	Amount Oxidized to Next Station	Correction	At Station, Corrected for Inflow	Observed at Station	Amount Contributed	At Station, Corrected for Inflow
Peoria (Mile 166.1)	—	387	—	—	—	387	303	—	303
Pekin (Mile 152.9)	Peoria pollution	716	117	5	112	604	102	—	102
Kingston Mines (Mile 145.5)	Mackinaw R. and Pekin pollution	602	95	8	87	515	112	2	110
Havana (Mile 119.6)	Spoon River	434	2	—	2	432	90	1	89
Beardstown (Mile 88.6)	Sangamon River	325	8	1	7	318	197	6	191

The analytical data for tributary streams was taken from U. S. P. H. S. *Bulletin* **171** which includes B.O.D. and D.O. results from the Spoon, Mackinaw and Sangamon Rivers for July and August, 1922.

Oxygen Balance and Reaeration

The term "oxygen balance" is used herein in accordance with the definition given in Part 111, Appendix 1 of the "Report of the Engineering Board of Review of The Sanitary District of Chicago on the Lake Lowering Controversy and a Program of Remedial Measures" (The Eddy Report). In this report, oxygen balance is defined as the "difference between the

quantity of dissolved oxygen and the quantity of oxygen demand in the river water at any station."

Table V is the basis for the determination of a gross rate of reaeration from which the total, gross amount of oxygen supplied by reaeration was estimated for each stretch. In this table, the change in oxygen balance taking place in each stretch is derived, giving due consideration to inflow between stations, whether dilution or pollution.

The stretch from Havana to Beardstown appears to be the logical one upon which to base reaeration estimates. Sludge deposits show less effect than in any other stretch and it is the only one in which an increase in dissolved oxygen takes place. Table V shows the "apparent net rate of reaeration" for the Havana to Beardstown stretch to be 2.16 pounds per 1,000 sq. ft. per day at an oxygen saturation of 37 per cent and a mean velocity of 1.11 miles per hour. This value is taken as the gross rate of reaeration for the stretch. Converted to the base rate at zero oxygen saturation, the above becomes 3.43 pounds per 1,000 sq. ft. per day at a velocity of 1.11 miles per hour, which figure agrees well with rates suggested by The Sanitary District of Chicago in other reaches of Illinois River.

Rates of reaeration in all stretches were computed by applying saturation and velocity corrections to the base rate of 3.43 pounds per 1,000 sq. ft. per day at zero saturation and at 1.11 miles per hour velocity. The rate of reaeration was assumed to vary as a straight line according to the degree of oxygen saturation, the rate being highest at zero saturation. Rates of reaeration were also assumed to vary as a straight line according to velocity, and the additional assumption was made that the aeration rate is 1 pound per 1,000 sq. ft. per day at zero velocity and zero saturation. This latter assumption appears permissible since it is known that reaeration does take place in still bodies of water.

The number of pounds of oxygen estimated to be absorbed by reaeration in each stretch is included in Table VI with data used in making the rate corrections for velocity and saturation. The station at Mile 162.0 is inserted here because it is desired later to refer the oxygen conditions at Mile 166.1 to Mile 162.0, which is immediately above the point of discharge of pollution contributed during this survey.

It will be noted that a total of 565,000 pounds of oxygen daily is estimated to be absorbed by atmospheric reaeration in the entire length of river studied (Mile 166.1 to Mile 88.6).

Oxygen Utilization

In this analysis, all oxygen utilization is classified under the two major components (1) that used in the oxidation of organic matter in suspension or in solution in the flowing river water and (2) that exerted by sludge deposits in any way, including "immediate" demand. The demand exerted by organic matter carried by the flowing water is computed by the relation:

$$X_w = L_B(10^{k_1 t} - 1),$$

in which X_w = demand exerted by organic matter in water and L_B

TABLE V.—*Illinois River Survey*

July 18–August 31, 1936

Net Changes in Oxygen Balance and Apparent Reaeration

Station	Water Surface Area (1000 Sq. Ft.)	Flow (c.f.s.)	Total Oxygen Demand				Dissolved Oxygen					Net Change in Oxygen Balance (Lbs. per Day)	Apparent Net Rate of Reaeration (Lbs. per 1000 Sq. Ft. per Day)
			Observed (P.p.m. at River Temp.)	Observed (Lbs. per Day)	Corrected for Inflow (Lbs. per Day)	Change Betw. Sta. (Lbs. per Day)	Observed (P.p.m.)	Observed (Lbs. per Day)	Change Betw. Stations (Lbs. per Day)	Deduction for Tribs. (Lbs. per Day)	Net Change Betw. Sta. (Lbs. per Day)		
Peoria (166.1)	—	8500	8.4	387,000	387,000	—	6.6	303,000	—	—	—	—	—
Pekin (152.9)*	127,150	8560	15.5	716,000	604,000	+217,000	2.2	102,000	−201,000	—	−201,000	−418,000	−3.28
Kingston Mines (145.5)	26,470	8630	12.9	602,000	515,000	−201,000	2.4	112,000	+ 10,000	2000	+ 8,000	+209,000	+7.89
Havana (119.6)	84,610	8740	9.2	434,000	432,000	−170,000	1.9	90,000	− 22,000	1000	− 23,000	+147,000	+1.74
Beardstown (88.6)	100,520	9110	6.6	325,000	318,000	−116,000	4.0	197,000	+107,000	6000	+101,000	+217,000	+2.16

* Laboratory data at this station subject to question.

TABLE VI.—*Illinois River Survey*

July 18 to August 31, 1936

Summary of Reaeration in Illinois River from Peoria to Beardstown

Section of River		Surface Area (1,000 Sq. Ft.)	Mean D.O. Saturation (%)	Mean Velocity (MP Hr.)	Gross Rate of Reaeration (Corr. for Velocity) (Lbs. per 1,000 Sq. Ft. per Day)		Total Reaeration (Lbs. per Day)
From	To				At Zero Saturation	At Observed Saturation	
Peoria (Mile 166.1)	Mile 162.0	97,460	80*	0.59‡	2.10	0.40	39,000
Mile 162.0	Pekin (152.0)	29,690	55†	1.00	3.18	1.44	43,000
Pekin	Kingston Mines (145.5)	26,470	28.4	0.93	3.05	2.18	58,000
K. M.	Havana (119.6)	84,610	26.6	1.07	3.34	2.46	208,000
Havana	Beardstown (88.6)	100,520	37.0	1.11	3.43	2.16	217,000
					Total		565,000

* Taken as constant through stretch.
† Mean, based on estimate of 80% at Mile 162.0.
‡ By float measurements.

= observed oxygen demand at the lower station (corrected for inflow). The normal biochemical values of k_1 at the river temperatures were used.

The pounds of oxygen demand thus computed as taking place in the flowing water in the stretch was deducted from the total amount of oxygen utilized in the stretch and the difference considered the demand exerted directly or indirectly by the sludge deposit. The total amount of oxygen utilized in each stretch was estimated by algebraic addition of the amount of oxygen absorbed by reaeration and the pounds of dissolved oxygen added or lost in the stretch. Table VII summarizes the oxygen

TABLE VII.—*Illinois River Survey—July and August, 1936*

Summary of Oxygen Resources and Utilization

Section of River	Oxygen Resources				Total Oxygen Utilized	Oxygen Utilization		
	D.O. in River Entering	D.O. in River Leaving *	D.O. Added or Lost in Stretch	Oxygen Added by Reaeration		B.O.D. Exerted by Flowing Water	B.O.D. Exerted by Sludge Deposits	Total B.O.D. Exerted
Peoria (Mile 166.1) to Mile 162.0	303	304†	+1	39	38	38	—	38
Mile 162.0 to Kingston Mines	304†	110	−194	101	295	98	197	295
Kingston Mines to Havana	112	89	− 23	208	231	165	66	231
Havana to Beardstown	90	191	+101	217	116	141	−25‡	141
				Totals		442	263	705

All figures represent thousands of pounds per day.
* Corrected for inflow.
† Computed. No sampling station here.
‡ Negative value indicates no appreciable effect by sludge deposits.

resources and liabilities in the various stretches and illustrates the methods employed.

It will be noted in Table VII that the conditions in the river at Mile 162.0 (which point is just above the various Peoria sources of pollution) have been estimated here by reference from the sampling station at Mile 166.1. This was done to simplify the demonstration of "oxygen sag" curves later. By computing the demand exerted from Mile 166.1 to Mile 162.0 (38,000 pounds per day) and using the reaeration value determined in Table VI for the same stretch (39,000 pounds per day), the observed B.O.D. and D.O. at Mile 166.1 was corrected to Mile 162.0. Thus determined, the B.O.D. at Mile 162.0 is computed to be 349,000 pounds per day (7.6 p.p.m.) at mean river temperature of 26.3° C. and the D.O. to be 304,000 pounds per day (6.6 p.p.m.).

The data observed at the Pekin station are omitted in Table VII and are not used in the ensuing computations because of the doubt concerning their reliability.

Concerning the apparent negative influence of sludge deposits indicated in Table VII for the Havana-Beardstown stretch, no ready explanation for this result is offered. Because the degree of the discrepancy is probably not great, considering the nature of computations of this kind, the interpretation given is that there is no appreciable sludge deposit in the stretch, which conclusion is supported by physical observations during the sampling period.

Table VII shows a total of 667,000 pounds of oxygen demand to be exerted daily in the stretch from Mile 162.0 to Beardstown, of which 263,000 pounds per day or 39 per cent is exerted by sludge deposits. Since sludge deposits appear minor in the river stretch between Havana and Beardstown, a better perspective of the overall effects of the deposits is brought out by study of the stretch between Mile 162.0 and Havana. In this reach, a total of 526,000 pounds of oxygen demand was exerted daily of which 263,000 pounds per day or 50 per cent was exerted by sludge.

Coefficients of Deoxygenation

A "composite" coefficient of deoxygenation (k_1) was computed for each stretch for use in determination of reaeration coefficients (k_2) because of the known presence of sludge deposits below Peoria and Pekin which would cause the actual rate of deoxygenation in the river to differ materially from the rate taking place in samples of river water incubated in the laboratory.

Values of (k_1) are computed as suggested by Streeter (*This Journal*, **7**, 543) by application of the relation:

$$k_1 = -\frac{1}{t} \log \frac{L_B}{L_B + X_t}, \qquad (1)$$

In which (t) is the time of flow in days, (L_B) is the observed B.O.D. at the lower station (corrected for inflow) and (X_t) is the total oxygen demand exerted in the stretch (from Table VII). The values of (k_1) thus computed follow:

Stretch of River	(k_1)
Mile 162.0 to Kingston Mines	0.276
Kingston Mines to Havana	0.183
Havana to Beardstown	0.138

The diminishing values of (k_1) indicate the tapering B.O.D. exertion by sludge deposits, which is shown to be inappreciable in the Havana-Beardstown stretch because the computed value of $k_1 = 0.138$ checks closely with the normal biochemical value $k_1 = 0.1398$ at a temperature of 27.3° C.

Coefficient of Reaeration

Values of (k_2) are computed by indirect substitution in the formula:

$$D_t = \frac{k_1 L_a}{k_2 - k_1}(10^{-k_1 t} - 10^{-k_2 t}) + D_a(10^{-k_2 t}), \qquad (2)$$

as outlined by Streeter and Phelps in Public Health *Bulletin* **146** (A Study of the Pollution and Natural Purification of the Ohio River). A modification regarding the manner of determining the initial oxygen demand (L_a) was employed, however, because of certain circumstances under which this data was collected.

In P. H. B. **146** it is suggested that the value (L_a) be based on "a mean (arithmetic) of the observed (L_B) and the residual component (L_A') of the observed (L_A) remaining at Station *B*." Had the analytical data available for this report covered a full year, so that averages covering all conditions of flow could be used, it is considered that this method would have been satisfactory. However, since the data were actually taken over a period of extremely low velocities when there was no scour, it is believed that the above method would not give a value of (L_a) that completely represented sludge deposits. In other words, it is felt that the river samples collected did not contain as much suspended matter (potential sludge deposit) as would be shown by a yearly average of B.O.D. determinations.

It is definitely known that considerable pollution was contributed during the winter preceding the sampling period but was discontinued before sampling was begun. The Penn-Maryland distillery operated all winter and suspended operation on June 27. The Hiram Walker distillery discharged half the thin slop produced to the river until early in July when the feed house installation was completed. The Terre Haute Paper Company operated during only April and May. Sludge deposited from these wastes, therefore, accumulated during the winter and undoubtedly exerted an appreciable demand during the summer months of the study, yet the above pollution was not represented in the samples taken.

Values for (L_a) are determined here by assuming that the total oxygen demand exerted (X_t) are represented by the total oxygen used in the stretch of river as found in Table VII.

For instance, in the stretch from Kingston Mines to Havana, a total of 231,000 pounds of oxygen was used daily. Then, by the relation:

$$L_a = \frac{X_t}{(1 - 10^{-k_1 t})}, \qquad (3)$$

(L_a) at Kingston Mines is computed as 675,000 pounds per day, the composite value $k_1 = 0.180$ being used.

It is appreciated that this method places a heavy burden on the gross rate of reaeration as determined by means of Table V, but for this study, this procedure is deemed advisable. Values of (L_a) thus derived follow:

Station	X_t (1,000 lbs. per day)	k_1	t (days)	L_a (1,000 lbs. per day)
Mile 162.0	295	0.28	0.72	798
Kingston Mines	231	0.18	1.01	675
Havana	141	0.14	1.16	455

Employing the above computed values of (k_1) and (L_a), coefficients of reaeration in the various river stretches are found to be as follows:

Stretch of River	t (days)	k_2
Mile 162.0 to Kingston Mines	0.72	0.35
Kingston Mines to Havana	1.01	0.32
Havana to Beardstown	1.16	0.35

Weighting these values for the time of flow in order to determine a mean value of (k_2) for the entire reach from Mile 162.0 to Beardstown, a mean $k_2 = 0.34$ is obtained (mean river temperature 27° C.).

While the value of (k_2) here determined is higher than that found by Streeter ($k_2 = 0.27$) for summer conditions in the stretch between Pekin and Havana (P. H. *Reports*, February 12, 1936, page 253), the difference may be due to the modifications used in computing the value here. As stated previously, these modifications were considered desirable because of the circumstances under which these data were collected.

Oxygen Sag Curve—Conditions of Survey

As a check on procedure heretofore, the oxygen content at each station is computed for comparison with the observed amounts. In substituting in equation (2), the individual "composite" values of (k_1) are used with the mean value of (k_2). The following computed and observed results are plotted in Fig. 2 on page 589.

Oxygen Sag Curve—Sludge Deposits Assumed Absent

The method employed in computing (L_a), previously described, offers an opportunity to show what oxygen conditions might have existed in the river at the time of the study had not the sludge deposit been present. The oxygen demand exerted by organic matter only in suspension or solution in the flowing water is shown by Table VII to be 404,000 pounds per day in the stretch Mile 162.0 to Beardstown. From this (L_a) at Mile 162.0 is computed to be 681,000 pounds per day. In developing an oxygen curve for this condition, the normal biochemical value of $k_1 = 0.135$ ($T = 26.5°$ C.) is used because of the assumption that sludge deposits are absent. (It will be recalled that the computed (k_1) for the

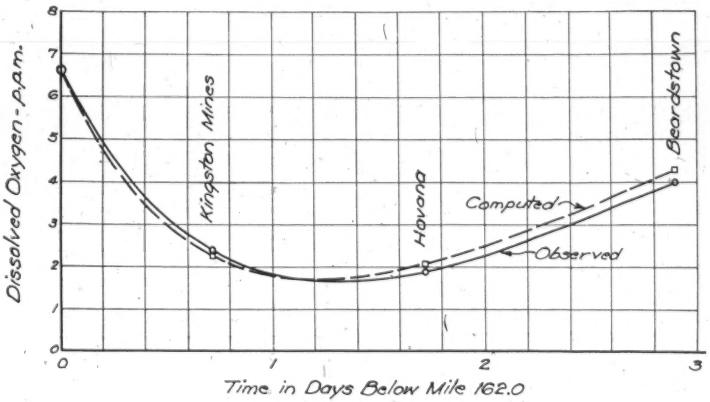


FIG. 2.—State of Illinois Sanitary Water Board. Illinois river survey, July 18–August 31, 1936. Oxygen conditions.

Station	k_1	k_2	Dissolved Oxygen (P.P.M.)	
			Computed	Observed
Mile 162.0			6.60	—
Kingston Mines	0.28	0.34	2.34	2.4
Havana	0.18	0.34	2.05	1.9
Beardstown	0.14	0.34	4.31	4.0

Havana-Beardstown stretch, in which the sludge deposit is not appreciable, closely checks the normal biochemical value of (k_1) at the prevailing river temperature.)

Figure 3 is plotted from the following computed oxygen contents at the various stations, the sludge deposit being assumed absent shown on page 580.

These results indicate that the oxygen content in the river below Peoria would probably not have fallen below 4.0 p.p.m. if the pollution discharged had been free of settleable solids (potential sludge deposits). Definite conclusions based on computations involving the above arbitrary assumption are, of course, unwise, but it is believed safe to conclude from this computation that the sludge deposits existent below Peoria during July and August, 1936, were largely responsible for the critical oxygen conditions observed.

Limits of Pollution

The object of this study was to determine the permissible total pollutional load at Peoria and Pekin which would not reduce the river oxygen content below 4.0 p.p.m. during critical periods of flow, with flow conditions similar to those prevailing in July and August, 1936. Because any pollution abatement program must first involve elimination of offensive

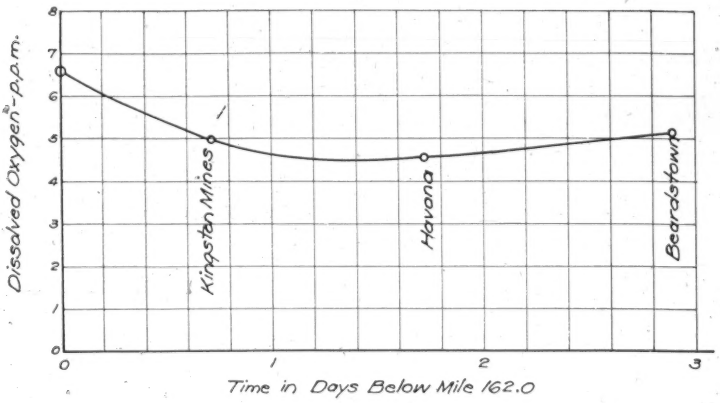


FIG. 3.—State of Illinois Sanitary Water Board. Illinois River survey, July 18–August 31, 1936. Computed oxygen conditions. Sludge deposits assumed absent.

Station	(k_1)	(k_2)	Computed Dissolved Oxygen (P.P.M.)
Mile 162.0			6.6
Kingston Mines	0.135	0.34	4.97
Havana	0.135	0.34	4.58
Beardstown	0.135	0.34	5.06

sludge banks, this estimation of permissible pollution is made with the assumption that the wastes discharged at Peoria and Pekin will not contain organic solids in such form that sludge deposits of material consequence will result. It is thus assumed that the absolute minimum degree of treatment to be provided all wastes will be such that nearly all settleable solids will be removed before discharge to the river.

To be conservative in this computation, a value of (k_1) slightly higher than the normal biochemical value of $k_1 = 0.135$ at 26.5° C., is assumed. An estimated value of $k_1 = 0.15$ is used since it is very improbable that all organic matter capable of producing a sludge deposit will be completely removed. The value chosen is considered to make allowance for any increase in the rate of deoxygenation which might result from the presence of a relatively small deposit.

The determination of a value of (L_a) at Mile 162.0 which represents the permissible limit allowing a minimum dissolved oxygen content of 4.0 p.p.m. at the critical point, involves trial and error procedure since the time of flow to the critical point is not known. By assuming trial values of (L_a) for substitution into the equation suggested by Streeter (*This Journal*, **7**, 548):

$$t = \frac{\log\left\{\frac{k_2}{k_1}\left[1 - \frac{D_a(k_2 - k_1)}{k_1 L_a}\right]\right\}}{k_2 - k_1},$$

and by substituting the resulting values of (t) in the "oxygen sag" equation (2) it is possible to obtain a final value of (L_a) which checks that originally assumed. By this procedure it was determined that a value of L_a = 680,000 pounds per day would result in a minimum dissolved oxygen content of 4.0 p.p.m. at a point 1.52 days below Mile 162.0.

During July and August, 1936, the B.O.D. content of the River above the sources of pollution was about 349,000 pounds per day which, deducted from the above value L_a = 680,000 pounds per day leaves a permissible pollution load of some 331,000 pounds per day at river temperature or 292,000 pounds per day at 20° C.

Future River Conditions

In the introductory remarks at the beginning of this report, it is pointed out that drastic changes in Illinois River below Peoria will take place by 1940. With the limited information available at present, it appears unwise to attempt any *definite* forecast of the future ability of the river to assimilate pollution for comparison with the present self-purification capacity as determined herein. However, a general discussion of the manner in which the more important hydraulic and pollution changes now under way in the river might be expected to affect conditions below Peoria does seem warranted, and the ensuing comments are offered with this intent.

Reduction in Flow

Diversion from Lake Michigan by The Sanitary District of Chicago must be reduced from 5,000 c.f.s. to 1,500 c.f.s. on December 31, 1938, in accordance with the decree of the United States Supreme Court of April 21, 1930. Under critical summer conditions such as existed in 1936 this reduction would lower the observed discharge of 8,500 c.f.s. at Peoria to about 5,000 c.f.s.

The following analysis of possible minimum flows shows, however, that a lower summer discharge might prevail at Peoria:

Source	Minimum Flow c.f.s.
Pumpage by Chicago	1700
Diversion from Lake Michigan	750
Desplaines River	9
DuPage River	—
Kankakee River	690
Fox River	154
Vermilion River	15
Direct Run-off to Illinois River	118
Municipal and Industrial Pumpage	150
Estimated possible min. 1940 flow at Peoria	3586

As it is not probable that all of the above minimum conditions would obtain simultaneously for any appreciable time, a reasonable future critical period discharge at Peoria of 4,300 c.f.s. is assumed.

Reduction in Chicago Pollution

The dissolved oxygen content observed in the river above Peoria in 1936 was 6.6 p.p.m., representing 80 per cent saturation at the observed temperature of 25.6° C.

Upon completion of the treatment works now under construction by The Sanitary District of Chicago, it is estimated by Langdon Pearse, Sanitary Engineer of the District, that between 6.98 and 7.48 p.p.m. of dissolved oxygen will be present at Chillicothe with a diversion from Lake Michigan of 1,500 c.f.s. Further increase in the dissolved oxygen content is to be expected in the 13 miles of flow from Chillicothe to Peoria and an estimated value of 8.0 p.p.m. at Peoria does not seem unreasonable. This would represent a saturation of 96 per cent at 25.6° C.

In spite of the expected increased dissolved oxygen concentration immediately above Peoria in 1940, the actual amount of oxygen available based on a flow of 4,300 c.f.s. would be only 186,000 pounds per day, whereas that observed in 1936 was 303,000 pounds per day at a flow of 8,500 c.f.s.

Physical Changes

Construction of the lock and dam at Mile 157.7 (just below Peoria), relocation of the La Grange lock and dam and dredging of the new 9-foot channel will completely revise the physical characteristics of the river and involves complete readjustment of the hydrometric data determined for 1936 conditions.

Information relative to the dams and dredging program, supplied by the Peoria office of the U. S. Engineer Corps, makes it possible to estimate surface areas, velocities and times of flow, assuming a 1940 critical season discharge of 4,300 c.f.s. These estimates are compared with those representing 1936 conditions in Table VIII.

TABLE VIII.—*Illinois River Report—July and August, 1936*

Comparison of Surface Areas, Velocities and Times of Flow for 1936 Conditions (Flow—8,500 c.f.s.) and 1940 Conditions (Flow—4,300 c.f.s.)

	1936				1940			
	Mile 162.0 to Mile 157.7	Mile 157.7 to K. Mines	K. Mines to Havana	Havana to Beardstown	Mile 162.0 to Mile 157.7	Mile 157.7 to K. Mines	K. Mines to Havana	Havana to Beardstown
Surface Areas (1000 Sq. Ft.)	14,640	41,140	84,610	100,520	19,320	37,794	72,575	98,190
Velocity (Miles per Hour)	1.03	0.95	1.07	1.11	0.36	0.63	0.64	0.52
Time of Flow (Hours between Stations)	4.2	12.8	24.2	27.9	11.9	19.4	40.5	59.6

According to Table VIII, surface areas and velocities will be appreciably less upon completion of the dams and dredging than during July–August, 1936. Times of flow will be increased in accordance with the velocity reductions. In general, water depths will not be materially

changed, averaging approximately 9 ft. under present and future estimated flow conditions.

Decrease in velocity below Peoria may be expected to (1) increase deposition of settleable organic solids and (2) reduce rates of reaeration from the atmosphere. Assuming a straight line variation between velocity and reaeration with a gross rate of reaeration of 1 pound per thousand sq. ft. per day at zero saturation and zero velocity (which assumption is made elsewhere in this report), the gross rate of reaeration in the Havana-Beardstown stretch, for example, would be only 2.15 pounds per 1,000 sq. ft. per day at zero saturation in 1940 as compared to 3.43 pounds per thousand sq. ft. per day determined for 1936 conditions.

The estimated reduction in water surface areas by 1940 will also lower the natural purification capacity of the river by reducing reaeration. The total surface area estimated for 1940 for the entire stretch from Mile 162.0 to Beardstown is 5.4 per cent less than the area computed during July–August, 1936. The only stretch showing an increase in water surface by 1940 is that from Mile 162.0 to the new dam located at Mile 157.7.

The lock and dam under construction at Mile 157.7 will have, upon completion, both a detrimental and a beneficial influence on the natural purification capacity of the river. The very low estimated velocity of 0.36 mile per hour through the pool behind the dam, into which all of the Peoria pollution will be discharged, will encourage deposition of sludge and particularly critical summer oxygen conditions would be expected here under pollutional loads comparable to those prevailing in 1936. The expected velocity would also tend to encourage ice formation in winter, consequently reducing atmospheric reaeration in the stretch during that season.

On the other hand, turbulence induced during flow through spillway gates of the dam creates conditions favorable to a rapid though brief absorption of oxygen from the atmosphere, the amount of such absorption being highest at zero oxygen saturation of the water entering the spillway. Based on studies made at Minneapolis-St. Paul (Second Annual Report, Minneapolis-St. Paul Sanitary District) it is estimated that from 2 to 3 parts per million of dissolved oxygen could be expected to be taken up in passage through the Peoria dam, consideration being given the expected discharge head, summer temperatures and oxygen saturation in the pool behind the dam. A 3 p.p.m. increase at a flow of 4,300 c.f.s. would yield 69,700 pounds of oxygen per day, which, added to the amount expected in the river above Peoria in 1940 (186,000 pounds per day), totals 255,700 pounds per day. It will be noted that this combined figure is still below the observed dissolved oxygen content of the river above Peoria in July–August 1936 (303,000 pounds per day) at a river discharge of 8,500 c.f.s.

Summary—Effects of Future Changes in River

It seems apparent from the above that the natural purification ability of Illinois River below Peoria will be notably reduced subsequent to the several changes which will have taken place by 1940. Opportunity for

atmospheric reaeration will be reduced, deposition of sludge deposits will be encouraged, and, despite the expected improvement in the quality of the water entering Peoria and the probable addition of oxygen in flowing through the new dam at Mile 157.7, it appears that less oxygen will be available to meet the immediate requirements of the Peoria and Pekin pollution.

It appears further that the most critical conditions in the future river under pollution loads similar to those existing in 1936 would be localized at and immediately below Peoria and Pekin, the greatly lengthened times of flow probably resulting in some decrease in the length of river seriously affected.

Summary and Conclusions

1. The data collected during the survey show definitely that critical dissolved oxygen depletion and resulting unfavorable dissolved oxygen balance existed in Illinois River between Peoria and Beardstown during July and August, 1936. Satisfactory river conditions were found to exist above Peoria.

2. The analysis made of the data indicates that the stretch of river between Mile 162.0 and Beardstown had a total reaeration capacity of some 526,000 pounds of oxygen per day under the prevailing flow conditions and that the coefficient defining the mean rate of reaeration in that stretch (k_2) is 0.34 (at 27° C.). The total B.O.D. exerted in the same stretch was estimated to be 667,000 pounds per day for the period of study.

3. It is further indicated that the critical conditions created during the period of study were due largely to the presence of sludge deposits between Peoria and Havana which exerted an estimated demand of some 263,000 pounds per day. This high value shows the cumulative effect of these deposits in that their greatest demand is exerted at time of critically low, summer river flows. It is estimated that if the sludge deposits had not been present, satisfactory oxygen conditions in the river might have been expected at the time of the survey.

4. A permissible limit of pollution at Peoria and Pekin is computed to be 292,000 pounds of 20° B.O.D. per day, which limiting value should not cause dissolved oxygen depletion to less than 4.0 p.p.m., *provided that only a moderate amount of organic matter capable of creating sludge deposits is present in the wastes discharged to the river.* This statement pertains only to flow conditions similar to those prevailing in the stretch of river at the time the data for this report were collected and is not meant to imply that only suspended matter removal from the industrial wastes by sedimentation or similar means would be adequate to insure permanently satisfactory river conditions.

5. Consideration of the qualitative and hydraulic changes in the river above and below Peoria which will have taken place by 1940 indicates that the permissible pollutional limit will be lower at that time than determined for 1936 conditions because of the probable reduction in natural purification ability of the river in 1940.

6. The abatement policy adopted for control of industrial pollution at Peoria and Pekin must include provision for the future. Without ques-

tion, a continued industrial growth can be expected in the area and the degree of treatment required at present must be sufficiently high to leave a material pollution assimilation capacity in Illinois River to care for future industrial development.

Wherever possible, depending upon the nature of the individual waste, provision for higher degrees of treatment may be made progressively as the rate of future industrial growth requires but a reasonable factor of safety must be maintained at all times to protect the river.

7. To prevent critical river conditions subsequent to December 31, 1938, it is obvious that settleable organic solids capable of producing sludge deposits must be removed to the greatest possible extent. In addition, an appreciable reduction in non-settleable organic matter is indicated if natural river purification agencies are to be expected to keep pace with deoxygenation.

No attempt will be made here to establish detailed immediate treatment requirements due to the individualized nature of the various industrial wastes involved. Also, in some instances, pollution reduction will be effected through by-product recovery or through process changes to reduce unnecessary losses in raw materials. Therefore, it appears much more logical to study each industrial problem separately so as to avoid any demands which might be unreasonable or impractical at this time.

Acknowledgments

The helpful advice and suggestions made by H. W. Streeter, Senior Sanitary Engineer, United States Public Health Service; Dr. F. W. Mohlman, Chief Chemist, Sanitary District of Chicago; Langdon Pearse, Sanitary Engineer, Sanitary District of Chicago; and L. S. Kraus, Chemist, Peoria Sanitary District, are gratefully acknowledged.

Field data were collected under the supervision of Carl D. Gross, Assistant Sanitary Engineer.

Laboratory determinations were made by John T. Barnhill, Chemist.

Assistance in assembling data was given by Sanitary Engineers R. S. Nelle and Leonard Dworsky.

Operators' Reports and Suggestions

W. D. Hatfield

219 Linden Place, Decatur, Ill.

DE KALB SANITARY DISTRICT, DE KALB, ILL.

Excerpts from Eighth Annual Report for the Year 1937

By Donald E. Henn

Superintendent

Sewage Flow

The total sewage flow for the year was 445.21 million gallons, of which 422.72 million gallons or 96.5 per cent were given complete treatment, 15.29 million gallons were by-passed with no treatment, and 7.20 million gallons were by-passed at the filters after primary treatment.

A total of 60.81 million gallons of plant effluent was returned to the raw sewage conduit during the canning season as diluting water, which was mixed with the strong raw sewage during dry weather when the canning plant was operating.

The treatment plant was in continuous operation during the year and no sewage was by-passed to the river except at times of storms when the sewage flow exceeded 2½ times the dry weather flow and the capacity of the plant.

The analytical data show the plant operated at a high efficiency throughout the year. A yearly average of 94 per cent reduction in suspended solids and 91 per cent reduction in the biochemical oxygen demand of the raw sewage was accomplished. The uniformity of the operation of the plant is attested by the small variation of monthly averages, for instance reduction of suspended solids, which varied between 91 per cent and 96 per cent during the year.

Plant Operation

Bar Screen.—The mechanically cleaned bar screen operated efficiently throughout the year. The building, screen channel and screen were cleaned at least once each week by flushing with a hose, and the screenings were removed daily. The motor on the mechanism was serviced and painted during February, and the only difficulty with this unit developed on December 16th when the mechanism stuck and stalled the motor, causing the motor to heat sufficiently before a fuse was blown to melt the insulating varnish off the wiring. The motor was removed, cleaned and repainted and put back on the mechanism on the 17th.

Grit Chambers.—The grit channels were cleaned once each week,

except during periods of high sewage flows when it is necessary to clean them more often, due to the quantities of grit which are washed into the sewers and to the flushing of low velocity sewers about town. All grit is flushed to sand drying beds and removed to be used as fill. No record is kept of the quantities of grit removed.

Primary Settling Tank.—This unit was in service throughout the year. Scum and all floating materials, grease, etc. were flushed to the skimming pit and then pumped to the digester. The tank was skimmed once each day during the warm summer months and as needed the rest of the year. The unit continued to give good clarification, the yearly average being 82 per cent removal of total suspended solids. From tests run every five days it is estimated that a total of 400 tons of dry solids were removed by this unit during the year. The influent and effluent channels of the tank were cleaned several times without dewatering or interrupting the service of the unit.

The return of plant effluent to the raw sewage conduit during periods of low flows and during the time the canning company is operating continues to prevent uncontrollable septic conditions in the unit.

Dosing Tanks.—These controlling units operated without difficulty throughout the year. They were kept clean by hosing down the sides and bottoms regularly.

The loose board winter cover was removed on March 10th and replaced on December 9th. The only item of maintenance of these units is on the 124 boards which make up this cover. The boards are painted each fall before being placed on the tanks as they are subjected to severe weathering while in use. In spite of the short time they are on the tanks each year and the care given them, 41 of the original 124 boards bought in the fall of 1930 have rotted or broken and have been replaced. The remaining 83 original boards are all getting weak and will have to be replaced very soon. The boards are sorted each year and those not fit for use discarded and new ones purchased. Thus far 12 boards have been the most that have had to be purchased any one year, 10 being bought this fall. By replacing a few boards each year this maintenance is spread and never becomes a large item of cost.

Filter Beds.—These biological units operated efficiently throughout the year and no ponding or clogging of the surface developed except in very localized, small areas late in the spring when the river was backed up over the underdrains and the sewage flow was high. This slight ponding caused no trouble as it never included as much as 5 per cent of the area of the beds and reduced itself as soon as the beds started to unload early in June. Very good reductions of the B.O.D. of the primary tank effluent were obtained throughout the year, the yearly average being 79 per cent.

The beds were rested alternately during September, each bed being by-passed four days, and all sewage was dosed to the other bed while one was being by-passed. This resting and drying out caused a noticeable unloading of the beds for a few days when they were returned to service. The beds started the fall and winter months in prime con-

dition and no difficulty is anticipated in their operation from ponding or clogging.

Secondary Settling Tank.—Due to high river flows, this unit was not put into operation until June 1st and was operated until December 1st. Some filter effluent was allowed to flow through the tank during December to prevent the formation of thick ice in the tank. The only repair necessary was to the power wires under the bridge on June 18th.

Sludge Pump (Dorrco).—This unit pumps raw sludge from the primary settling tank to the digester. No change in the method of pumping was tried as the automatic operation for 15 minutes each at 1:00 p.m., 10:00 p.m. and 3:00 a.m. and manual operation from 15 to 45 minutes each morning and afternoon gives a very equal loading of the digester over the 24 hours, removes sludge from the primary tank every few hours, and yet gives the sludge in the digester time to settle between pumpings.

During February the motor was serviced and painted inside and out with insulating varnish and the drive chains cleaned and inspected. No noticeable wear was observed on these chains after seven years of service.

Digester.—Considerable time and thought were given this unit during the year. While no serious difficulty was experienced in its operation, several conditions developed which needed attention. In February the liquor in the digester was covered with a rather thick and deep scum. In July, due to the quantities of humus sludge added from the secondary tank, the digester filled with a very thin sludge and the overflow became heavy. Quantities of sludge were drawn to the drying beds and 125 lbs. of lime were added on July 30th. The digester settled down early in August and caused no further difficulties due to bulking sludge. As reported in the 1936 report, it became evident during the winter of 1936 and '37 that the heating coils in the digester were covered with a hard sludge cake which had reduced their efficiency in transferring heat to the point where suitable temperatures could not be maintained in the unit. Plans were formulated early in the year to drain and service this unit some time during the early fall. On the 8th of September all was ready, and this unit was drained and serviced and put back into operation on September 19th. While the digester was out of service the sludge storage tanks were used as digesters and the operation of the plant was not interrupted.

Sludge Drying Beds.—The regular sand sludge drying beds were used to dry sludge from the digester during the summer months. A total of 62 beds of sludge, each 8 to 10 inches deep, was drawn between March 23rd and October 27th. In April the beds were all serviced and three beds were rebuilt.

The three auxiliary sludge drying beds, with a combined area of 9150 sq. ft., were used during the summer season to dry the sludge which had been accumulated in the storage tanks. These units, consisting of leveled areas with dirt dikes, are becoming very uneven and deeper each year and will have to be rebuilt in the near future.

De Kalb Sanitary District Monthly Report on Plant Operation 1937

Description	Unit	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Aver. Monthly
Sewage Flow															
Treated	M.g.	54.62	34.21	39.86	56.43	44.98	40.86	31.85	31.58	24.70	25.84	18.80	18.99	422.72	35.22
By-passed—At First Street	M.g.	5.65	1.94	0	5.23	.50	1.8	.17	0	0	0	0	0	15.29	1.27
At Filter—Primary Treatment	M.g.	0	3.00	0	2.38	0	.92	.90	0	0	0	0	0	7.20	.6
Total Sewage Flow	M.g.	60.27	39.15	39.86	64.04	45.48	43.58	32.92	31.58	24.70	25.84	18.80	18.99	445.21	37.09
Average Treated per Day	M.g.	1.76	1.22	1.28	1.88	1.45	1.36	1.03	1.02	.82	.83	.63	.61	—	1.16
Temperature															
Average Temperature—Sewage	° F.	50.6	49.5	49.8	49.2	55	60.3	67.4	71	68	65	62.7	61	—	54.5
Analytical Data Raw Sewage															
Suspended Solids Total	P.p.m.	213	185	226	192	239	290	341	440	332	398	400	411		305
5 Day B.O.D.	P.p.m.	125	80	197	172	177	198	294	439	404	268	360	282		250
Primary Tank Effluent															
Suspended Solids Total	P.p.m.	43	42	46	45	44	56	63	61	62	51	49	56		51.5
5 Day B.O.D.	P.p.m.	44	46	67	65	65	158	120	144	158	98	127	110		102
Per Cent Reduction—Suspended Solids	%	80	77	80	77	82	81	81	86	81	87	88	86		82
Per Cent Reduction—B.O.D.	%	65	43	66	62	54	20	59	67	61	63	65	61		57
Filter Effluent															
Suspended Solids Total	P.p.m.	19	17	14	9	10	182	110	28	84	48	15	22		46.5
5 Day B.O.D.	P.p.m.	17	13	19	23	12	25	24	29	42	16	14	18		21
Per Cent Reduction—Suspended Solids	%	11	14	14	19	14	—	—	8	6	1	8	9		10.6
Per Cent Reduction—B.O.D.	%	22	41	24	25	39	67	33	26	29	31	31	33		33
Plant Effluent															
Suspended Solids Total	P.p.m.	19	17	14	9	10	30	24	17	23	17	15	22		18
5 Day B.O.D.	P.p.m.	17	13	19	23	12	16	20	25	32	1F	14	18		19
Dissolved Oxygen	P.p.m.	9.8	9.5	8.4	7.2	7.0	4.8	4.1	3.5	3.5	5.2	8.4	9.0		6.7
Total Per Cent Reduction—Suspended Solids	%	91	91	94	95	96	90	93	96	93	96	96	95		94
Total Per Cent Reduction—B.O.D.	%	87	84	90	87	93	92	93	94	92	94	96	94		91
Dry Solids Removed/Cap./Day	Pounds	.344	.206	.272	.345	.333	.35	.328	.434	.26	.317	.243	.237		.306

Population connected 8300.
"A" Station in operation 14 days.
"B" Most of gas wasted at digester (Not metered).
"C" Digester drained on Sept. 8, to clean heating pipes. Six feet of seed sludge pumped to it on Sept. 17. No other sludge drawn during month.

Plant eff. returned to raw sewage conduit for dilution

Month	M.g. in Days		Cannery Operating
July	16.79	17	16 Days
Aug.	22.46	21	21 Days
Sept.	21.56	19	14 Days
June			8 Days
Total	60.81	57	59 Days

An additional temporary sludge lagoon was made early in September by slipping out a hole just east of the auxiliary beds. This lagoon was filled with sludge from the digester when it was drained.

Canner's Circulating Pump.—This unit, owned by the California Packing Corp. and located at the District's Plant and operated by the District, was used on 57 days between July 8th and September 20th under the same method of operation as that used each year since and including 1934. A total of 60.81 million gallons of plant effluent were returned to the raw sewage conduit with a power input of 8138 K.W. Hrs. which cost $122.07, or $2.02 per million gallons pumped.

Canning Wastes

The canning company operated their plant on 59 days between June 22nd and September 15th inclusive. Peas were packed on 8 days during June, starting on the 22nd, and 16 days in July, completing the pack on the 21st. Corn and lima beans were packed on 21 days in August, starting on the 7th, and on 14 days in September, completing the year's operations on the 15th.

Although the canning company enjoyed a very successful season, canning well over one-half million cases of 24 cans each, of corn alone, no unusual difficulty was experienced in handling the canning wastes. The recirculating pump was operated on 57 days to return a total of 60.81 million gallons of plant effluent to the raw sewage conduit, and this method of operation continued to prevent a recurrence of the serious operating difficulties experienced the first few years the treatment plant was in operation.

As reported elsewhere in this report, the treatment of canning wastes is still a major problem in many localities in the country and DeKalb is fortunate that due to local conditions this problem has been solved in this District, at least for the time being.

APPENDIX I

Report on the Draining, Repairing and Servicing of the Digester Unit

De Kalb Sanitary District, De Kalb, Illinois

September, 1937

For the last year or year and a half it has been becoming increasingly evident that the heating coils in the digester were coating with a cake that was insulating the coils and reducing the transfer of heat. During the winter of 1936 and '37 the temperature in the digester dropped below efficient digesting temperatures, and it became evident that it would be unwise to attempt to face another winter season without attempting to at least return the existing heating coils to their original efficiency.

All sludge in the digester was drawn to the storage tanks and all water and scum to the drying beds. The digester was then pumped full of plant effluent to purge it of gas and this water was then drawn to the drying beds where it soon drained through the sand.

An air blower rated at 1200 cu. ft. of air per minute was set over one of the manholes of the digester to blow through a 20-in. pipe to the bottom of it. This gave a theoretical change of air every 18 minutes. This fan was started on the afternoon of September 11th, and ran continuously for 40 hours before any attempt was made to enter the tank. The fan was run continuously until the work was completed.

Monday, September 13th, several sparrows were trapped and lowered into the tank in a cage and left there all day without any adverse effects. This gave assurance concerning the condition of the air in the bottom of the unit.

The only unforeseen difficulty arose Monday a.m. when it was discovered that one of the scum breaker arms was bent very badly. After a hurried conference it was decided to remove both scum breaker arms, as it was agreed that the real scum arms were in the bottom of the tank. The removal of the arms made it necessary to construct staging in the tank, cut out the arms, and then remove the staging in sections. This work required three days. Thursday, September 16th, work was started on cleaning the cake off the existing heating coils and the installation of a new coil. The cake on the existing coils averaged ⅝ of an inch thick and was made up of very definite laminated layers. No difficulty was experienced in breaking this cake off of the pipes, less than 8 man hours being required to clean 380 ft. of 1¼ inch pipe.

The existing heating coil in the digester consisted of three 1¼ in. pipes hung on the wall of the round tank, each pipe being 125 ft. long, starting and ending in a header. A connection was made in the pipe from the return header and one 2-in. pipe connected to it and carried around the digester and back to the return pipe to the heating unit in the office. Thus all hot water pumped through the heating unit will circle the digester first through one of the three 1¼ in. pipes and then a second time through the 2-in. pipe. It is estimated that this will increase the heating capacity by about one-half. This additional heating pipe was installed for two reasons—one immediate, the other permanent. Previously the average temperature in the digester could be raised only about 2° F. per week in mild weather, and held constant in cold weather, with a loss of temperature during the severe months of the winter. Then it was necessary to start the winter with high digester temperatures in order to have digesting temperatures above 70° F. by spring. It was also necessary to carry high temperatures in the heating coils, which added to the caking, with resultant loss in heat transfer. Because it was necessary to do this work in the fall, making necessary the filling of the digester with relatively cold water late in September, it was evident that with the existing heating unit a sufficiently high temperature could not be obtained in the digester before cold weather to carry over until spring. With the additional heating

coil it was hoped the temperature could be raised more rapidly and then maintained. The second and more important reason for the addition was that much lower temperatures can now be carried in the heating coils with the resultant reduction in caking of sludge on the heating pipes.

At 10:30 a.m. on September 17th, just nine days after work was started, the work was completed and the sludge pump started pumping seed sludge to the digester.

During the time the digester was out of service all raw sludge was pumped to the storage tanks which had been well seeded with sludge from the digester. When work on the digester was completed, digesting sludge from the tanks was pumped to the digester, raw sludge added to it and filled with plant effluent. The digester was full at 8 a.m. September 19th and was producing gas at the rate of 142 cu. ft. per hour, which increased gradually to 384 cu. ft. per hour, or 9200 cu. ft. per day, by September 23rd. The temperature of the sludge on September 19th, was 73, the pH 6.8, and volatile matter in seed sludge 46 per cent of dry solids. The heater and circulating pump were started on September 19th and by October 2nd the temperature of the sludge had raised to 87° F., the average temperature to 84.4° F. and the pH to 7.0 without the addition of lime, and the digester had settled down to normal operation.

This rather difficult and dangerous work was completed without an accident of any kind to either man or equipment and without loss of efficiency of the plant. Two laborers were hired to assist the regular plant personnel of superintendent and helper.

THE MINEOLA SEWAGE TREATMENT PLANT*

By Frank H. Hall

Chief Operator, Sewage Treatment Plant, Mineola, N. Y.

The Village of Mineola could be rightly called the "Hub" of Nassau County; located as it is half way between the north and south shores of Long Island. Its rapid growth can be attributed to its fine roads, its wonderful train service and the fact that it is the county seat of Nassau County.

The population in 1920 was 3,016; in 1925, 5,240; in 1930, 8,139 and in 1937 over 11,000.

The Village is located on what was once called the Flatlands of Nassau County and there is only 15 ft. difference in elevation between the highest and lowest points.

In 1928 the taxpayers voted for a sewerage system and disposal plant and in August of that year construction started. The plant was finished in October, 1929, and in operation November 1929.

* Presented at the Fall Meeting of the New York State Sewage Works Association, Elmira, N. Y., October 15–16, 1937.

The activated sludge plant was designed to handle 1 m.g.d. from a population of 10,000.

All but a small portion of the village sewage drains to a central pumping station in the Village Park on Garfield Avenue. There the sewage enters the sump through a 24-in. sewer to a "Y" channel. On each branch of the "Y" there is a basket screen through which the sewage flows before reaching the pump section. Now a word as to these baskets. When the plant opened we had the regulation basket with all its cleaning horrors. A basket was built by connecting two 24-in. hoops with ¾-in. by 5/16-in. iron straps 3 ft. long, bent over and spot-welded at each end to the hoops. These straps are placed 6-in. to centers. One-inch poultry wire 3 ft. wide is then cut to the right length to line the inside of the basket. The bottom of the basket being solid, all sewage must pass through the 1-in. mesh wire. The basket is hoisted out of the pit by a hand operated portable derrick, swung over a truck and lowered on its side. The wire rod lacing the ends of the poultry wire together is pulled out. The poultry wire is pushed away from the basket sides and the derrick hook is taken off the handle of the basket and placed on the bottom hoop of the basket. The basket is then hoisted bottom side up and the screenings slide into the truck. The saving in labor more than offsets the cost of wire.

The raw sewage is chlorinated during the six warm months of the year by a Wallace and Tiernan Vacuum Type Chlorinator; the average use of chlorine is 31 lb. daily. Three A.C. motor-driven vertical centrifugal pumps of 1, 2 and 2.5 m.g.d. capacity handle the raw sewage and deliver it to the treatment plant, a mile away, through an 18-in. cast iron main. (Note—Since the opening of the plant the 2 m.g.d. pump handled practically all of this sewage until it was taken out of service for repairs on August 25th of this year.) All pumps are float-controlled. A standby gasoline driven electrical generator, capable of handling all three units in an emergency, is also installed in the pump house.

The disposal plant is located on the State Place just off Westbury Avenue. The blower house faces north and the tanks are located to the west of the house, extending east and west.

First comes the four digesters with a total capacity of 30,700 cu. ft., with their access manholes forming an opening in the center of the square formed by the four tanks, through which inlet and overflow valves are operated. These tanks are 23 ft. by 20 ft. each, the long dimension running north and south, and average 15 ft. deep. They have solid concrete decks. All openings in the tanks are projected below the surface of the liquid so that all gas is trapped and gathered in a gas dome and piped to filters and flame traps and from there to boilers used to heat circulating water for the heating coils of the digesters.

These tanks were without heat originally but we had to install heating coils to keep the plant operating efficiently. About 1,200 ft. of galvanized W. I. 2½-in. pipe was ordered cut to 20 ft. and 10 ft.

lengths, respectively, and frames were made of 6 by 6-in. lumber to hold the pipes, in a manner somewhat similar to the posts of a rail fence. Four sets of posts were made for each tank, and they were painted with hot tar after holes had been drilled for bolts. These holes were so drilled that each pipe had a slight pitch and after all were in place the bolts were tightened, forming what looked like a fence in the tank, enclosing an area 10 ft. by 20 ft. and five pipes high, using 300 lin. ft. to a tank. The bottom of the posts rested on the tank floor. Each pipe end was reduced to 1-in. and from there to central control valves and heater all piping is 1-in. with all exposed pipe covered with three-cell asbestos pipe covering, a layer of hair felt and wrapped with waterproof paper. This gives good results and in winter the temperature of the sludge can be taken by reading the temperature of the return water. In 1936 we added an oil-fired water heater to help maintain the temperature in the digesters in winter and by keeping the temperature as close to 80° as possible we had fine results.

Lime is added to the digesters by feeding it to the top of this tank in solution, while pumping as required to keep the reaction neutral or a little above. We have found it best to feed lime while pumping the preliminary tank to the digester. One bag daily is required for each of the three preliminary tanks, and one bag per 7,000 gal. of return sludge pumped to the digester. All liming is done by lime solution. One or two bags are dumped into the lime solution tank which is kept agitated by air and then pumped to any part of the plant the operator may see fit. This way of handling lime has given no trouble whatsoever. All lines are flushed out with clear water when through using.

Between the digesters and the three preliminary settling tanks comes the raw sewage channel. Total capacity of the three preliminary tanks is 50,000 gallons, providing a detention period of 1.2 hr. for 1.0 m.g.d. Four 8-in. outlets in the bottom of the channel over each tank (24 in all) distribute the raw sewage evenly in a downward direction of flow to each of the three tanks. Located directly under each outlet is a hinged baffle held at an angle by a chain extending to the top of the tank. This baffle deflects settleable solids to the center of the preliminary tanks. A wooden baffle extends above and below the level of sewage in the tanks, and prevents floating solids from entering the effluent channel. Sludge scrapers in the preliminary tanks are used twice daily; once at 7:30 a.m. for 20 minutes to agitate and settle raw sludge and again at 1 p.m. when the tanks are pumped clean. As the raw sewage is pumped intermittently great care is taken to start the scrapers a short time after pumping stops so that the solids have a chance to settle before pumping starts again. All washing of tanks and breaking up of floating solids is done at the same time so that the smallest amount of solids reach the settled sewage channel and from there to the activated channel. The settled sewage channel is kept agitated by air at all times so that solids will not settle and become septic.

Before I go further let me state we get best results from inter-

mittent pumping, although great care must be taken to get just the right amount of pumping, that is to pump often with a short idle period, not to set the floats to get too large a quantity at one time. We are now averaging 17,000 gallons per pumping.

At the south end of the settled sewage channel is a mixing chamber where the settled raw sewage meets the reaerated return sludge from the air lifts.

After flowing through the mixing chamber the mixed raw settled sewage and return sludge flow into five aeration tanks which have a capacity of 220,000 gallons and a detention period of about five hours with 1.0 m.g.d. flow.

We also feed lime daily to the activated sludge. The lime solution is fed through pipes to channels 1, 3 and 5 and we try to maintain a pH of 7.2, which in our case requires one bag of lime to each 225,000 gallons of sewage.

Lime not only has a chemical effect on the sludge but the small grains become attached to the floc and help settle the sludge in the final tank. Not long ago we had a laundry in the village and the chemicals they used raised the pH so much that we could not feed lime. After much experimenting clay was used and this seemed to do the job weighting the floc down but as these fine particles of clay were also highly abrasive, its use was discontinued and a very fine settled silt was used. We have no laboratory to speak of so we take the simpler tests for dissolved oxygen, stability, pH, percentage of settled solids, and therefore most of our work is done along practical lines. We classify the floc in the activated as light, normal and heavy; bearing in mind at all times that the oxygen demand of our settled raw sewage where it mixes with the return sludge is the biggest factor. Yet the D.O. content of the effluent compared with the D.O. of the influent to the final tanks tells us sometimes hours in advance what will happen if we don't do certain things, and I, for one, owe Mr. Gilcreas a vote of thanks for his simplified amidol D.O. Test.

Rate of flow, or B.O.D. of incoming raw sewage, and temperature control the percentage of sludge in the activator. During summer months when the aeration tanks have temperatures over 70° and the flow is greatest, we keep the percentage of sludge between 18 and 24. In the winter when the temperature drops to 48 and the flow slackens we keep the sludge up to 28 and 36 per cent. Dissolved oxygen tests are taken often in summer, because, as we use chlorine for odor control only, stoppage of sewage in a main line, if only for an hour, puts a big load of highly septic sewage on the plant and the system must then be lightened to give this sewage all the air possible.

Carborundum porous tubes 5½ ft. below the surface of the activated sludge are used to diffuse the air.

After passing through the aeration tanks the activated sewage and sewage flows into a channel which diverts it equally into the two final settling tanks. The floc settles to the bottom of the tank where it is scraped to the center and picked up by the air lifts, put back into cir-

culation again or wasted to a digester. The clear effluent flows over 160 ft. of V-notch weirs per tank to the effluent channels and from there to any of the eight percolation beds 110 by 125 ft. each.

Our effluent has been of such a high order that at no time during the past year was more than one bed wet and we are cleaning our percolation beds now for the first time since June of this year.

Deming Cross, operator, takes a great deal of interest in the plant and much credit is due him for the assistance he renders in the good performance of our plant.

RAHWAY VALLEY, NEW JERSEY, JOINT MEETING SEWAGE TREATMENT WORKS

EXCERPTS FROM FIRST ANNUAL REPORT

June 1 to December 31, 1937

BY NORMAN C. WITTWER

Supervising Sanitary Engineer

The first part-year of operation of the sewage treatment works was conspicuous by the comparative freedom from the many operating difficulties generally associated with the tuning-up of plants of this character. This reflects great credit upon the Joint Meeting and its consulting engineers for the thoroughness and painstaking care with which the entire project was initiated and carried through to completion. However, we have not been entirely free from operating kinks. Most of these have been mechanical and hydraulic rather than biological in nature, and have either been satsfactorily adjusted, or are in the process of being solved.

Design Capacities.—All trunk sewers are designed for the estimated maximum flows in 1960, when flowing full. Capacities increase progressively toward the sewage treatment works, where the capacity of the 72 in. diameter trunk sewer is rated at 55 million gallons per day. The individual treatment plant units have the following design capacities:

Grit Chamber	55.0 m.g.d.
Mechanical Screen	55.0 m.g.d.
Sewage Pumps	56.0 m.g.d.
Settling Tanks	12.5 m.g.d.
Digestion Tanks	75,000 persons
Drying Beds	75,000 persons
Outfall Sewer	55.0 m.g.d.

Connected Population.—Accurate figures on the number of persons connected into the system are difficult to obtain. The quantity of industrial wastes in 1937 was relatively small. In general, these wastes were unobjectionable from the standpoint of plant operation. Therefore, they will not be reduced to an equivalent population load. The following estimate is believed to be reasonably correct.

	Connected Population in 1937	Probable Connected Population in 1938
Town of Westfield	16,000	16,000
City of Rahway	—	17,000
Township of Cranford	9,000	12,000
Borough of Garwood	3,600	3,600
Borough of Roselle Park	600	600
Township of Springfield	5,000	5,000
Borough of Kenilworth	1,100	1,100
Township of Woodbridge	3,200	3,200
Township of Clark	700	900
Totals	39,200	59,400

Sewage Treatment Works

General.—As was to be expected so soon after the completion of the plant, very few repairs to the mechanical equipment were necessary during 1937. A contract was let in November for a number of miscellaneous improvements to the plant. These included pipe railings for the settling tanks and the steps to the digestion tanks, grit chamber and grease chamber; steel plate covers over the emergency screen; wire guards for the mechanically-operated screen and No. 4 sewage pump motor; a pipe railing in front of the switchboard; and other safety devices. In addition, handwheel operated gates were included for the inlets to each of the nine settling tank compartments. Cypress baffle plates are to be installed at the settling tank outlets. As of December 31st, the installation of the above equipment had not begun.

Plant Performance.—The entire plant performed very satisfactorily the functions for which it was designed. Table I shows the average flow, power cost, chlorine used, and operating cost. Two yardsticks of overall performance have been used, each somewhat dependent upon the other, viz:

Table I.—*Summary of Operating Data*

Month 1937	Average Daily Flow M.g.	Average Daily Flow per Capita Gal.	Rainfall In.	Power Cost per M.g.	Average Chlorine Dosage † P.p.m.	Operating Cost ‡	Operating Cost per M.g. Flow
June	5.64	143	—	$2.10		$2115.05	$12.50
July	5.48	139	—	1.90	6.9	3250.58	19.16
Aug.	7.35	186	7.84	1.73	7.2	2875.13	12.60
Sept.	6.43	163	3.39	1.86	6.4	2969.35	15.45
Oct.	6.11	154	4.67	1.90	9.1	3279.00	17.30
Nov.	8.37	212	5.04	1.57	7.7	2607.32	10.40
Dec.	8.48	215	1.37	1.68		2692.40	10.25
Aver.	6.83	173		1.79	7.5	$2826.98	$13.55

* No records obtained.

† July to October inclusive.

‡ Includes cost of trunk sewer maintenance.

(1) The removal of solid material, including wet settleable suspended solids, grit, screenings and grease, amounted to an average of 185 tons per month or 6 tons per day. This was approximately 75 per cent of the total suspended solids entering the plant.

(2) The reduction in biochemical oxygen demand averaged 42 per cent, or from 3.2 tons per day in the raw sewage to 1.8 tons in the effluent.

Grit Chamber.—The grit chamber has performed its functions very efficiently to date. Under normal conditions, little evidence of grit was noticeable in the sludge withdrawn from the settling tanks. Only during periods of extremely heavy flow did appreciable quantities of grit pass through the grit chamber to be deposited in the settling tanks. The average quantity of grit removed from the sewage daily by the grit chamber was 1,650 pounds. Except during storm flows, the average quantity of grit per day was approximately 1,500 pounds. During heavy storms, the quantity of grit removed has been as high as 7,900 pounds per day, or 3.95 tons.

The grit platform, onto which the grit is discharged, was found to be too low, flooding to a depth of a foot or more during periods of high tide or heavy rain. A new concrete platform was constructed on the old platform, raising the working level two feet. No difficulty due to flooding has since been experienced.

Screening.—The mechanically-cleaned screen was entirely free from trouble or repairs. The total amount of screenings removed from the sewage averaged 470 pounds per day. This quantity is equivalent to 69 pounds per million gallons of sewage flow, or 12 pounds per day for each 1,000 persons connected into the system.

The incinerator has not been used for the destruction of screenings as it was found by experience that the relatively small quantities of screenings obtained during the year could be more economically disposed of by burying in the meadows which form part of the plant property.

Chlorination.—Chlorine was applied to the sewage up to the first week in November, at which time permission was received from the State Department of Health to discontinue the application from October 15th to May 15th of each year. Varying strengths of chlorine dosage were experimented with during the period chlorine was used. Chlorine demand tests were run daily in order to correlate periodic variations in the strength of sewage with the quantities of chlorine required to produce the necessary chlorine residual required in the effluent by the State Board of Health. Experiments up to the end of the year indicate that a probable dosage of 10 parts per million will be required to produce a positive residual in the effluent at all times.

Settling Tanks.—551,814 cubic feet, or 1,740 tons of wet settleable suspended solids were removed from the sewage by the settling tanks. Unit quantities of solids removed were as follows:

Average per month	85,500 cu. ft.
Average per day	2,790 cu. ft.
Average per capita per day	.071 cu. ft.

All of this material was pumped into the digestion tanks.

The combined removal of settleable suspended solids by the three settling tanks, acting in parallel, was 71.7 per cent of the settleable suspended solids in the incoming raw sewage.

Sludge Digestion.—Effective control of sludge digestion has been obtained by careful regulation of sludge additions and withdrawals, and by routine laboratory analyses. Lime was added in a milk of lime solution, when necessary, to raise or maintain the pH of the digesting sludge above 7.0. The temperature of the primary digesters was maintained well above 80° F. at all times. The average amount of suspended solids in the supernatant liquor was 892 parts per million.

Trouble was experienced from the beginning with the primary digester sampling pipes. The sampling pipes were so constructed that the lower ends of the pipes were flush with the tank ceilings. This gave rise to two problems:

(1) Foaming sludge bubbled through the sampling pipes, sometimes in sufficient quantities to spread over a considerable area of ground.
(2) Loss of gas was occasioned by a sufficient drop in the level of the sludge to permit the generated gas to escape through the sampling pipes directly into the atmosphere.

This condition was corrected by inserting 7-inch pipes inside the 8-inch sampling pipes, the 7-inch pipes being extended 3 feet below the tank ceilings. The air space between the 7-inch and 8-inch pipes was caulked gas-tight with lead wool. Since the change was made, all of the troubles have disappeared.

Foaming occurred in the primary digesters on several occasions. This was corrected by the withdrawal of sludge from the bottom of the tanks and recirculating it back into the inlet pipes, meanwhile running the turbo-mixers continuously. Addition of milk of lime to the recirculated sludge also aided materially in the reduction in or elimination of foaming.

The following summary is for the six and one-half months period from June 16th to December 31st, starting with digestion tanks on June 16th which contained for the most part heated raw sewage, with very little sludge.

Raw wet sludge pumped to digesters	551,814 cu.ft.
or	17,500 tons
Total solids in raw sludge (5.5%)	963 tons
Volatile solids in total solids (70.1%)	675 tons
Mineral solids in total solids (29.9%)	288 tons
Volatile solids in digested sludge (46.7%)	252 tons
Total solids in digested sludge (6.2%)	540 tons
Total wet digested sludge	870 tons
or	279,000 cu.ft.
Reduction in total solids	44.4 per cent
Reduction in volatile solids	63.3 per cent
Sludge withdrawn to drying beds	187,500 cu.ft.
Supernatant liquor withdrawn	283,000 cu.ft.

Gas Production and Utilization.—Due to the adjustment required in the gas relief pot, measurement of the total gas production was im-

possible during 1937. The new gas relief valve was installed in December, and immediate measurement of the total quantity of generated gas was begun. Gas measurements to date indicate an average daily gas production of approximately 50,000 cubic feet, or 1.27 cubic feet per day per capita.

The average heating or fuel value of the gas was 570 B.t.u., slightly higher than that of artificial gas, but lower than that of natural gas.

Sludge Drying and Final Disposal.—A partial blockage occurred in the 8-inch cast iron sludge line between the digestion tanks and the drying beds. One new manhole was constructed at the end of the line, and another is under construction at the angle in the line just west of the drying beds. The completion of these manholes will greatly facilitate the maintenance of this pipe line.

187,296 cubic feet of wet sludge were applied to the drying beds. Both the open and covered beds were used as occasion demanded. Our experience has shown that in the warm summer months, sludge dries to a forkable condition much more rapidly on the open beds than on the covered beds. During the late fall and winter months, however, drying is more rapid on the covered beds.

The average time required for drying sludge varied from 21 days in July and August to 57 days in November and December. Freezing weather in December facilitated the removal of sludge which otherwise would have been too wet to handle.

Approximately 10,000 cubic feet of forkable sludge was removed from the beds. A small quantity of this sludge was ground for fertilizer purposes. A large quantity of the dried sludge was removed from the beds by Rahway Reformatory labor, and taken in their trucks to the Reformatory farm.

Several analyses of the sludge cake indicated an organic nitrogen content of approximately 2 per cent, based on the dry weight.

Maintenance of Grounds.—The plant property within the fence is extensive, with a considerable area of lawn and embankments. As was to be expected, a few improvements were necessary to bring the ground to a serviceable condition. The major improvements were as follows:

(1) A concrete curb was constructed at the north end of the roadway alongside of the service building. A new concrete dish-gutter was constructed from the end of this curb, down the embankment and into a new inlet adjacent to the grit chamber platform. From this inlet a 6-inch terra cotta pipe was laid a distance of about 60 feet to a point of discharge in the meadow.

(2) Approximately 1,500 square feet of stone foot paths were constructed in and around the plant units with materials left by the contractor who built the plant.

(3) A considerable area of land from outside of the fence drains across the lawns and down the embankments. During heavy rains, washouts occurred at a number of places in the new embankments. In order to alleviate this condition, a drainage ditch was dug outside of the fence for the full length of the property east of the entrance gate. This

ditch has intercepted all water from outside of the fence and has reduced washouts considerably. However, still further corrective measures will be necessary in order to finally remedy this condition.

(4) A concrete ramp was constructed up the embankment adjacent to the garage to facilitate the passage of men and tools up to the level lawn above the embankment.

Due to the late planting of grass seed, the grounds required very little attention until the first of September. From that time on until the last week in October, two men were employed continuously on ground maintenance.

Shrubbery and small trees were planted at various locations around the Service Building and other portions of the property. The shrubs are a mixture of Rhododendron, Azalea, and other evergreens.

Miscellaneous.—Several miscellaneous items pertaining to the operation of the plant may be of interest.

(1) The service water pumps for pumping outside service water and for pumping water to the chlorinators use settled sewage for this purpose. Considerable difficulty was experienced with the clogging of street washers on the outside lines, and with the clogging of the duplex strainers on the chlorine injector lines. A drum type screen was constructed of ⅛-inch copper wire mesh and placed over the inlet to the service water line. The installation of this screen has reduced clogging difficulties to a minimum.

(2) Drain piping was installed for the sludge pump and for the service water pumps. The installation of this pipe eliminated the continuous spilling of water over the floor and facilitated the maintenance of the boiler room floor in a tidy condition.

(3) The sump pump which was installed to automatically dewater the building sub-structure by means of an old construction sump has proven extremely satisfactory. Since this pump has been placed into automatic operation, all evidence of leaks due to ground water in back of the building walls or under the floors has disappeared.

Cost of Trunk Sewer Maintenance.—The summary of cost given below includes the cost of obtaining the sewage flow measurements as this cost is not directly chargeable to the sewage treatment plant. It also includes one half of the cost of maintenance of mobile equipment, the other half being justly chargeable to the cost of operating the sewage treatment plant.

(1) Cleaning sewers and siphons	$1,532.06
(2) Sewage flow measurements	371.49
(3) Maintenance of mobile equipment	115.49
(4) Inspection of new connections	58.88
Total	$2,077.92

Sewage Flow Measurements.—Sewage flow measurements were made during the 30-day period from November 10th to December 9th,

1937. Existing gauging stations, using rated sewer sections, were used for measuring the flows.

From the measured flows, the average daily flow of sewage contributed by each member municipality was determined. The results of these sewage flow measurements were made the subject of a special report dated December 15, 1937.

Pursuant to instruction given on August 26, 1937, a comprehensive study of the problem of accurately measuring the sewage flows from the member municipalities was undertaken. The purpose of this study was to establish a method or methods of sewage flow measurement which would guarantee reasonably accurate results, and an equitable division of Sewage Treatment Plant and Trunk Sewer annual operating costs. The results of this study were embodied in a special report dated November 16, 1937.

Summary

The results of the first part-year of operation may be summarized as follows:

(1) The operating organization has been successfully organized.

(2) The treatment plant performance obtained has been consistent with that intended by its designers.

(3) The Rahway River has already shown physical evidence of great improvement.

(4) Maintenance costs, either on a per million gallons treated basis, or on a per capita basis, have been reasonable, and somewhat lower than those of other treatment plants and systems in this area serving like purpose.

Editorial

OXYGEN DEMAND OF SLUDGE DEPOSITS

The most objectionable feature of a grossly polluted stream is the presence of floating, gas-lifted sludge, foul in odor and nauseous in appearance. Abatement of stream pollution should always be directed first to the removal from sewage of the settleable solids, and second to the reduction of the B.O.D. of the clarified sewage. Although it is generally accepted that clarification accomplishes about 35 per cent reduction of B.O.D. and complete treatment 90 per cent, the actual benefit to the stream by clarification may greatly exceed 35 per cent, particularly in the early months of summer.

Stabilization of sewage sludge deposits on stream beds is accomplished at the expense of the dissolved oxygen of the supernatant water. The well-known accelerating effect of comparatively small increases in temperature on the rate of oxygen demand of sewage also applies to sludge, and when the water temperature reaches 15 to 20 degrees Centigrade in June, a sudden increase in the oxygen requirement of sludge deposits occurs. For a few weeks the sludge deposits may erupt violently and the river surface may be covered with a carpet of bubbling sludge. Later in the summer, the water temperature may reach 30 degrees Centigrade, and as the temperature mounts, the sludge continues to putrefy, although not with the explosive violence associated with the onset of summer weather.

For a long time it has been known that the oxygen demand of freshly settled sewage sludge is far greater than that of digested sludge, or of stream deposits several years old, but there have been comparatively few investigations of the rate of B.O.D. of sludge. In the past few years, however, attention has been directed toward this subject at a number of research laboratories in the United States. Results of investigations of B.O.D. of sludge and river mud have been reported by Rudolfs, Fair, Theriault and Baity, the latter in this issue (page 539). Studies have also been under way since 1935 in the laboratories of the Sanitary District of Chicago and undoubtedly similar work has been carried on elsewhere.

Dr. Baity's paper on the results of his work at Harvard in 1925 is very interesting, and he has studied more phases of the problem, at one time, than other investigators. He started with raw sewage sludge, with a high volatile content, and with very thin layers, ranging from .089 to 4.0 centimeters in depth. The experiments were carried on for only 36 days. As Dr. Baity states, it is recognized that this period was too short to establish many factors related to the long-time incubation required for the complete stabilization of sludge deposits of appreciable depth. The curve of oxygen in his Fig. 2 is ended with the statement "oxygen demand essentially satisfied," but it seems to the writer that this conclusion is subject to doubt, and if the tests had been continued, the oxygen demand might have continued indefinitely, and the total after a year or two might have been double the 36-day total.

Other studies, on somewhat different bases, and with deeper layers of sludge, have been continued to 400 days (Rudolfs) and 700 days (Sanitary District of Chicago). The results of Dr. Rudolfs' study are given in an abstract in this issue (page 636). A somewhat casual consideration of the results of both studies shows the following:

Days at 20 deg. C.	Mgm. 5-day B.O.D. per Gm. Volatile Solids	
	Rudolfs	San. Dist. Chi.
0	540	380
40	380	270
80	320	210
120	270	170
200	190	140
400	110	105
600	—	97
700	—	96

The rate after 40 days was approximately 70 per cent of the initial rate in both cases, while even after 400 days, the rate was still 20 to 28 per cent of the initial. During a summer period of about 120 days, the rate might therefore decrease to about half the initial. During the following winter the sludge would remain practically dormant, and through the following summer the rate would again decrease to about one-half of the initial rate of the second year. After this, the rate would apparently remain more or less constant for a number of years, at 100 mgm. 5-day B.O.D. per gm. of volatile solids. A number of well-digested sludges from the Illinois River have averaged around this value. The sludge beds studied by Rudolfs, in the Connecticut River below Springfield, Massachusetts, also averaged approximately 100 mgm. per gm. volatile solids.

Dr. Baity gives a 10-day B.O.D. for the Brockton sludge of 244 mgm. per gm. volatile solids, equivalent to approximately 180 mgm. on a 5-day basis. This is lower than the values found by Rudolfs and the Sanitary District of Chicago for fresh sewage sludge, but higher than has been reported for sludge from river bottoms.

Notwithstanding these variations, which may be ascribed to the effect of different techniques, the fact remains that a procedure is being developed and data are being accumulated that will enable us to evaluate the effect of sludge deposits in stream studies. Even with sewage treatment, sludge banks will be formed from storm-water discharge. With data based on the organic content of sludge, we can in time evaluate the influence of such deposits.

The influence of sludge in the lower reaches of the Illinois River has been discussed briefly by Wisely, who states on page 569 of this issue that in the stretch from Mile 162 to Havana (Mile 120), 50 per cent of the total oxygen demand was exerted by sludge deposits. The Board of Review of the Sanitary District of Chicago estimated that the sludge deposits in the upper Illinois River exerted an oxygen demand in summer that was equivalent to the total flow of sewage, thus doubling the load on the oxygen resources of the river.

The consensus of those who have studied the oxygen demand of sewage sludge seems to be that by far the greatest source of deoxygenation is caused by freshly settled sludge, deposited during the winter months and throughout the current summer. Such deposits, when allowed to pass through another winter, will show a greatly reduced rate of demand during the second summer. Dr. Imhoff once suggested to the writer that under some conditions it might be desirable to skim off the surface of lake bottoms early in the spring, in order to remove sludge deposited during the previous winter. Such vacuum cleaning has not been accomplished, so far as the writer knows, but there is a great deal of significance in this suggestion.

It is fortunate that so many investigators are studying the oxygen demand of sludge deposits, with reference to stream conditions, and our efforts to abate stream pollution will be on a sounder foundation when we have more information on this important subject.

F. W. M.

Proceedings of Local Associations

TEXAS WATER AND SEWAGE SHORT SCHOOL

Twentieth Annual Meeting

College Station, Texas, February 14–18, 1938

The Twentieth Annual Short School, held under the auspices of the Texas Division, Southwest Section, American Water Works Association, Texas State Department of Health, and Texas A. & M. College, proved to be one of the most successful held in recent years. The course, which was given at the Texas A. & M. College at College Station, Texas, under the direction of Mr. E. W. Steel, Professor of Municipal and Sanitary Engineering, lasted from February 14 to February 18. About 250 persons were in attendance representing about 100 Texas cities.

The instruction was divided into three divisions: a water superintendents' section, a sewage treatment and stream pollution section, and a laboratory section.

Probably one of the most successful features of the recent school was the holding of the many informal round-table evening discussion groups. Many plant operators who could not be persuaded to make themselves heard in a regular session were only too eager to deliver their opinions in these informal discussions.

Sewage Treatment Section and Stream Pollution

The high-light of the School was no doubt the Sewage Section which met on Thursday and Friday. Among the principal speakers were Mr. J. K. Hoskins, Senior Sanitary Engineer, United States Public Health Service; Major E. A. Wood, Director Texas State Planning Board; the Honorable Conde R. Hoskins, Chairman of the Legislative Committee on Stream Pollution; and Colonel E. D. Rich, Chief Sanitary Engineer of the Michigan State Department of Health. The Section opened with a symposium on Stream Pollution, its origin, consequence, and possible methods of control. The Michigan program for the licensing of sewage treatment plant operators was discussed in some detail by Colonel Rich.

Other topics considered were the "Securing of Sewer Connections" by Mr. H. E. Hargis, Texas State Health Department, and Mr. A. E. Stein, Sanitary Engineer with the City of Bryan. These papers pointed out in detail how house-to-house canvasses were made and how the general public was educated to coöperate and to desire to connect their premises to the municipal sewer system. The method of approach to the individual householder and also statistics dealing with the number of sewer connections that had been secured in the city as

the result of this particular work was brought up. Mr. E. A. Baugh, Chief Engineer, Works Progress Administration for the State of Texas, delivered a particularly interesting discussion regarding the assistance that the Works Progress Administration would extend to the State municipalities to improve their sewer system facilities, and included the construction of a sludge drying bed, treatment plant operation, additional settling and digestion capacity, and the extension of sewer mains and laterals. "The Dallas Sewage Treatment Program," by Mr. A. P. Rollins; "The Treatment of Milk Plant Waste," by Mr. Oakes T. Turner, Sanitary Engineer; and "Chemical Treatment of Sewage," by Mr. C. E. Yaffee, of the El Paso Disposal Plant, were particularly interesting in that they presented definite figures and data on these specific problems. Mr. Wm. Pralle, Sewage Engineer with the City of Houston, pointed out the results of experiments designed to assist in the operation of an overloaded activated sludge plant with a chlorine application to the return sludge at an average rate of 5.34 p.p.m. which was followed by considerable improvement in the quality of the plant effluent, a distinct reduction in the number of sphaerotilus in the sludge, and considerable alleviation of bulking difficulties. Mr. A. P. Honcock, City Manager of Kerrville, discussed the farm owned by the City, upon which is placed the effluent of the Imhoff Tank disposal plant. In addition to irrigation of feed stock, hogs are fed on garbage and sheep are grazed upon the pasture section of the farm area. Annual gross profits for the four year period 1934–1938 for the value of crop and stock returns over farm operating expenses were $465.31. The operation of the Kingsville Sewage Irrigation Treatment Plant was described by Mr. R. L. Peurifey, City Engineer, and Professor at Texas A. & M. College. Sewage from 6,000 contributing population is passed through a coarse bar screen and is applied as an irrigant directly on to approximately 120 acres of land or disposed into a 12 acre lake where it is stored for future use in irrigating land adjacent to the lake. Considerable success has been had with the growing of rhodes grass. Operating cost exclusive of depreciation and interest on the plant amounts to $0.24 per person per year and excellent financial rates are obtained from the irrigated land.

Mr. J. C. Oliver of Floydada presented a well received paper which dealt with the operation problems of the small sewage treatment plants. This paper pointed out methods of detecting grease and oil flowing into sewers, a newly developed type of grease trap, control of foaming in an Imhoff Tank, and described all odor and maintenance problems. Several symposiums of stream pollution were held throughout the sewage treatment session, including the showing of stream pollution slides, prepared by the University of Texas, Division of Visual Instruction. Mr. E. L. Filby presented a set of photographs and slides showing the construction of the new Denver Sewage Treatment Plant, and discussed its effect on the control of stream pollution.

The members of the sewage session presented for adoption a resolution requesting the State Department of Health to institute a course

of instruction, both through itinerant teachers and correspondence, for training sewage plant operators; the resolution further requested that plans be instituted by the State Department of Health along the lines of the sewage plant operation to give the operator credit for knowledge and qualification, to provide greater stability in employment and recommendation with the municipality in an effort to produce better trained personnel. These resolutions were adopted by the general body.

Laboratory Section

This section, which ran concurrently with the other two divisions, laboratory tests for both water and sewage plant control and operation were discussed and demonstrated. In addition to bacteriological, chemical, and other physical tests, one period was devoted to the making of threshold determinations for odor control.

Annual Banquet

The annual banquet, held Thursday night, was attended by approximately 250 persons. In addition to the participants of the School there were present, Doctor Geo. W. Cox, State Health Officer, who delivered the main address of the evening and Doctor W. P. Harrison, Chairman of the State Board of Health. Dr. Cox discussed at some length the plans which had been made by the Water Works Fraternity within the State which had been climaxed at this meeting by the issuance of The Water Works Manual, and he went on further to outline a program for future work which would carry on the record, already set by the water works and sewage men of Texas.

The Honorable Conde R. Hoskins, Chairman of the Legislative Committee on Stream Pollution, with great fervor, portrayed a picture of the pollution, not only existent in our Texas streams, but that which would result if adequate treatment and control measuures were not adequately carried out. Mr. Hoskins stated his belief that no City regardless of its size or its industry, notwithstanding its economical importance to the area, has the inherent right to pollute a public stream or in any way make that stream water indisposable for use by any individual living thereon.

Before the close of the banquet Mr. V. M. (Vic) Ehlers, Texas State Sanitary Engineer, was called upon to take the floor and review the many years work of the Short School which had been culminated in the publication and distribution of a comprehensive Water Works Manual.

New Officers and Resolutions

The following officers were nominated by the nominating committee and elected by acclamation by the organization:

Mr. J. L. Horner, Henderson, *President.*
Mr. V. M. Ehlers, Austin, *Secretary.*
Mrs. Earl H. Goodwin, Austin, *Assistant Secretary.*

Mr. A. G. Classen, El Paso, *First Vice-President.*
Mr. D. B. Dickson, Wichita Falls, *Second Vice-President.*
Mr. S. C. Clark, San Benito, *Third Vice-President.*
Mr. M. J. Salmon, Commerce, *Fourth Vice-President.*

A resolution was prepared providing for the coöperation of some state school or some other institution in the establishment of a laboratory together with sufficient competent personnel for the study, testing, and approval of plumbing facilities and appliances and the formulation of codes and regulations for their design, manufacture, and installation. Another provided for the appointment of a committee of qualified persons to advise with the State Department of Health in promulgating a program for the training and licensing of sewage treatment plant operators and superintendents. The Committee on Water Purification devices and purification processes recommended that all such devices be thoroughly investigated and studied in a Laboratory to be set up at either the University of Texas A. & M. College, or some other suitable State Institution, before presented for approval by the Water Works School. Before the close of the School, licensing examinations for those eligible men desiring to take them were supervised by Dr. W. T. Gooch, Chairman of the Licensing Committee. Approximately 20 men took advantage of this opportunity to acquire their license. It was with considerable pride that Dr. Gooch pointed out that the State now had over 500 licensed Water Works Operators.

V. M. Ehlers, *Secretary*

KANSAS WATER AND SEWAGE WORKS ASSOCIATION

Eleventh Annual Meeting

Lawrence, Kansas, March 24–26, 1938

The eleventh annual meeting of the Kansas Water and Sewage Works Association was held in the Engineering Building of the University of Kansas, Lawrence, Kansas, on March 24–26, 1938.

The total registration was 124.

Prior to this meeting, from March 21–23, a short school was held during which time lectures and laboratory work were given relating to water and sewage treatment.

The papers dealing with sewage treatment were: "Physical Hazards in Water and Sewage Treatment" by Charles C. Dills; "Water and Sewage Works Under P.W.A." by R. J. Paulette; "Recent Developments in Sewage Treatment" by R. E. Lawrence; "The Biology of Trickling Filters and Activated Sludge" by W. C. Purdy; "The Detection and Measurement of Stream Pollution from the Standpoint of Aquatic Life" by Paul D. Haney; "Stream Pollution Control" by L. F. Warrick; "Financing Sewage Treatment Costs" by A. B. Martin; and "Treatment and Disposal of Industrial Wastes" by L. F. Warrick.

A round table discussion of stream pollution and sewage treatment problems in Kansas was held on Friday afternoon, following the formal papers.

The annual banquet was held in the Union Building of the University of Kansas, at which time Dr. E. H. Lindley, Chancellor of the University, greeted the group. An illustrated lecture by A. D. Aldrich of Tulsa, Oklahoma, followed the banquet. His subject was "Practical Fisheries Management on Municipal Lakes and Reservoirs."

At the annual business meeting the following officers were elected: *President*, H. L. Lingo, Horton; *Vice-Presidents*, R. R. Sparks, Troy, W. O. Myers, Ottawa, F. A. Rathert, Junction City, and A. F. Regier, Moundridge; *Secretary-Treasurer*, Earnest Boyce, Lawrence.

EARNEST BOYCE, *Secretary*

MICHIGAN SEWAGE WORKS ASSOCIATION

Thirteenth Annual Conference

East Lansing, Michigan, March 30–April 1, 1938

The annual conference of the Michigan Sewage Works Association was held at Michigan State College, East Lansing, Michigan, March 30, 31 and April 1, 1938, following the annual short course which was held the first two and one-half days of the week. 7 were registered at the conference in addition to 26 of the 58 who attended the school but who were unable to stay over the remainder of the week. This was the largest attendance at the Michigan conference on record. In addition to excellent papers given by Michigan members, the Association was particularly fortunate this year in being able to secure three outstanding men from outside the state for the program.

The conference was opened by a very cordial welcoming address by Pres. Robert S. Shaw of Michigan State College.

The following papers were presented: "Operating Experiences and Results of First Year's Operation at Ann Arbor" by Harold P. Dodge; "First Impressions of Sewage Treatment in Neighboring States" by Robert J. Smith; "Jackson Sewage Plant Operation" by R. A. Greene and R. B. Jackson; "Natural Stream Purification as Applied to Practical Measures of Stream Pollution Control" by H. W. Streeter; "What's New and Interesting in Sewage Treatment" by L. H. Enslow; "Picturing an Industrial Plant Disposing of Its Wastes" by T. J. Powers; "Comments on Sewer Rental in Ann Arbor" by Geo. H. Sandenburgh; "Application of Laboratory Analyses and Studies to Plant Operation" by E. Hurwitz; and "Design Features of the Lansing Sewage and Garbage Treatment Plant" by W. R. Drury.

The annual banquet was held on Thursday evening at which time Dr. O. R. Yoder, Assistant Superintendent of the Ypsilanti State Hospital, gave an address entitled "Mental Health in the Community."

A feature of the program consisted of group discussions, the selec-

tion of the group being a choice of the individual member. This point of the program has been instituted as a substitute for the "Question Box" in an effort to secure participation by a greater number of individuals in the discussions. A gadget contest was held, the prize awards being won by the operators at the Muskegon and Pontiac plants. An inspection of the Lansing plant, now approaching completion, concluded the program.

At the annual business meeting H. P. Dodge of Ann Arbor was elected President; Allan Kronbach, Monroe, Vice President; L. F. Oeming, Michigan Stream Control Commission, Director for 1938–39; W. F. Shephard, Michigan Department of Health, Secretary-Treasurer; and W. L. Mallmann, Michigan State College, continues in office as director for the year 1938.

W. F. SHEPHARD, *Secretary*

FEDERATION RESEARCH COMMITTEE REPORT

COMMENTS BY CLINTON L. BOGERT

Mr. Clinton L. Bogert, of the firm of Sanborn and Bogert, Consulting Engineers, 30 Church Street, New York, has requested that the following letter be published. It was submitted to Professor Phelps and his reply follows. *Editor.*

April 12, 1938

Professor Earle B. Phelps, Chairman
Committee on Research
Federation of Sewage Works Associations
College of Physicians and Surgeons, Columbia Univ.
168th Street and Broadway
New York, N. Y.

Re: Danbury Treatment Works

Dear Professor Phelps:

May we ask you to take what steps you can to correct the wrong impression of the economies of the Danbury treatment plant project in your Committee report in the March 1938 issue of the SEWAGE WORKS JOURNAL, where you arrive at the conclusion:

"one wonders whether fine screening and settling at the hat works might not have been equally effective, saved the cost of a new plant, and reclaimed waste fur with a by-product value."

Your Committee should have had the following facts before them in shaping the conclusion:

1. Danbury is one-industry town.
2. There are about 30 hat and fur establishments scattered over the City.
3. When we suggested individual plants in 1923, the spokesman for the manufacturers replied that they were the chief support of the City and that the treatment of the industrial wastes was a municipal responsibility.
4. The State Water Commission (William R. Copeland, Chief Engineer) gave the City of Danbury a mandatory order to improve the sewage treatment plant.
5. At the same time, some 12 or more plaintiffs appeared in suit against the City (before these plant improvements were completed) claiming damages for injuries arising from pollution of the stream.

In the circumstances the City of Danbury had no choice but to extend the plant.

You may be interested in the exceptionally good results obtained at the enlarged Danbury plant, as shown by the State Department of Health tests. At the time of the tests neither chlorine nor lime were being applied.

Point of Sampling	Suspended Solids		B.O.D.		Alkalinity	
	P.p.m.	Per Cent	P.p.m.	Per Cent	P.p.m.	pH
November 2, 1937						
Inlet to Fine Screen	210		320		4	4.4
Outlet Settling Tanks	91	52	150	53	61	6.3
Outlet Trickling Filter	30		13		49	6.9
Outlet Final Tank	27	87	13	96	55	6.9
February 1, 1938						
Inlet to Fine Screen	190		260		4	4.6
Outlet Settling Tanks	64	66	170	35	52	6.2
Outlet Trickling Filter	42		44		39	6.7
Outlet Final Tank	23	88	22	91	43	6.9

Yours very truly,

C. L. Bogert,
Sanborn and Bogert

Copies to Messrs. Emerson, Faber, Enslow, Scott and Copeland.

Reply by Professor Phelps

I note with interest Mr. Bogert's list of facts which are submitted for the guidance of our Research Committee in correcting "The wrong impression of the economics of the Danbury treatment plant project in your committee report. . . ." Apart from Item No. 3 it would not appear that these facts have any bearing upon the selection of any particular remedy. Admittedly the plant was overloaded and pressure was being brought upon the city to improve the situation. Admittedly also, Danbury is a one industry town and there are about thirty hat and fur establishments scattered over the city.

The question of the economics of the solution, which is the only question raised by Mr. Bogert, would seem to be adequately disposed of in his Item No. 3. From this it appears that he himself had suggested individual treatment plants and that the suggestion was vetoed by the "spokesman for the manufacturers." It would seem, therefore, that the first proposal of the engineers, presumably based upon sound economics, was vetoed as a matter of practical or possibly political expediency.

The above are my personal views, as I have not thought it necessary to submit Mr. Bogert's communication to the committee membership, all of whom reviewed and approved our report before publication.

Earle B. Phelps

Reviews and Abstracts

H. W. Streeter

EXPERIMENTAL RAPID FILTRATION AT HUDDERSFIELD

By Dr. H. H. Goldthorpe

Abstract, *The Surveyor*, **93**, 365 (1938)

Discussion, *The Surveyor*, **93**, 385 (1938)

Following the recently reported work in America on high rates of dosage of trickling filters, experiments have been conducted at Huddersfield with high-rate trickling filters, having in mind the use of the process particularly as a preliminary treatment for the strong English sewages.

The experiments at Huddersfield were made by dosing two identical filters, one at 10 and the other at 20 m.g. per acre per day of settled sewage from a single orifice box. The filters consisted of 8 ft. long by 2 ft. diameter concrete pipes placed vertically on 9 in. concrete collars and filled to within 1 ft. of the top with 2 to 4 in. size hard clinker. A false concrete floor with 1 in. circular holes at 2½ in. centers supported the medium and some half dozen holes were made through the collar below the false floor to provide additional ventilation. Settled sewage was pumped to a 15-gallon constant head orifice box from which two sharp-edged circular orifices (5/16 and 7/16 in.) fitted into 2 in. risers controlled the rate of flow, adjustments in the rate of flow being obtained through variation of the head on the orifices by screwing the pipe risers up or down in the orifice box. The orifices discharged into rotary distributors made (as discussed by Mr. Wishart) by "extending the axle of a bicycle hub and attaching a brass can 3½ in. diameter by 6 in. deep, fitted with two ½ in. brass tubes about 9 in. long and drilled with holes."

The time of flow through the filters was obtained by adding 250 cc. of saturated sodium chloride solution to the distributor cans, sampling the effluent 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 20, 25, 30, 35, etc., minutes later and determining the time required for half the added salt to pass through the filters. Routine catch samples of settled sewage and filter effluent were taken daily, the influent being taken from the orifice box and the effluent being sampled after an interval of time corresponding to the time of flow through that filter. These times of flow varied from 20 to 25½ minutes and 7 to 9 minutes for the filters dosed at 10 and 20 m.g. per acre per day respectively, the peak periods of salt concentration occurring at about 7 and 2 minutes respectively.

Local ponding of the beds occurs and migrates from place to place, but no general ponding was observed. *Psychoda* congregate under the ponded portions protected from the heavy wash, lay their eggs and the larvae make short work of the blockage. The growths on the surface of the bed may interfere with ventilation but have never hindered purification. With slightly warmer conditions, the fly life increases until the beds are nearly stripped clean; then most of the *Psychoda* larvae are washed out, after which the growths rapidly increase until fly life is again re-established. Rainy week ends and holiday periods cause a light colored filamentous growth which might prove troublesome if such conditions were normal. During dry weather it is believed that filter temperatures will remain high enough to provide sufficient *Psychoda* development to keep the bed open, and during periods of melting snow and cold, wet weather the sewage fortunately carries a smaller load.

The pH of the settled sewage, normally about 4.5, was raised to 6.5 by adding lime. The average amounts of settleable (Imhoff cone) suspended matter in the effluent from

each filter is about the same. Based on 4 hour oxygen absorbed from permanganate, the percentage purification was 30 per cent for bed (*a*), dosed at 10 m.g., and 20 per cent for bed (*b*), dosed at 20 m.g. per acre per day. The Huddersfield plant, itself, gives a maximum of 70 per cent purification. Figures for the latter part of the run approached a value of 40 per cent purification for filter (*a*). The B.O.D. values, using 200 p.p.m. $NaHCO_3$ in stored tap water for dilution, were variable but averaged 55 per cent purification for filter (*a*) and 45 per cent for filter (*b*), and also showed improvement toward the end of the run. To obtain the relative purification of rapid filtration and chemical coagulation, the settled sewage was treated with 100–160 p.p.m. of aluminum sulfate, the results being as follows:

	Oxygen Absorbed		5-day B.O.D.	
	P.p.m.	% Purif.	P.p.m.	% Purif.
Settled sewage	204		160	
Filter (*a*)	138	31.6	72	55.4
Filter (*b*)	161	21.4	90	44.7
Clarified settled sewage	177	13.7	78	53.1

A tabular comparison of the effect of the increased dosage on filter (*b*) compared to (*a*) is as follows:

	Filter (*a*)	Filter (*b*)	Ratio (*a*)/(*b*)
Time of contact—minutes	22	8	2.75
4-hour oxygen absorbed, per cent purif.	30	20	1.5
5-day B.O.D., per cent purif.	55	45	1.22
Lbs. oxygen demand/acre/day removed:			
4-hour oxygen absorbed permang.	6,300	8,400	.75
5-day B.O.D.	8,800	14,000	.63

Discussion.—Mr. J. M. Wishart (Shipley) stressed the applicability of rapid filtration as a preliminary process and its advantages in ironing out irregularities in sewage composition, and questioned the author regarding the effects of temperature and sewage colloids and whether any subsurface filter sampling had been done. Dr. Goldthorpe replied that with warm sewage on cold days the ventilation through the bed was upwards, causing a hoar frost to collect on the pipe above the beds, but keeping the bed sufficiently warm for good activity by *Psychoda* larvae. He thought that a sewage freer of colloids would have less tendency to pond but might show less percentage of purification. The beds had been disturbed to a depth of a foot on only a few occasions but at those times the interior seemed to be cleaner than the surface.)

Mr. M. Lovett (West Riding Rivers Board) pointed out that in the daily results the net removal was frequently greater with a higher value of the applied sewage and suggested that this might be due to the removal of only the most easily oxidized fraction of the total demand. He thought the divergence between permanganate and B.O.D. test was not unusual, but wondered if a more complete picture might not be obtained by using the oxygen absorption from dichromate. Dr. Goldthorpe replied that the filter did remove much the same percentage of the oxygen-consuming bodies rather than a fixed quantity, regardless of the sewage strength. No nitrogen determinations had been made.

Mr. H. H. Stanbridge (Pudsey) wondered how much of the success and the free-

dom from filamentous growths had been due to previous removal of colloidal matter and grease by prior acidification. He stated that the filter at Pudsey only ponded during wet and winter weather. He pointed out that the filters were in operation from August 2d, whereas the recorded results started September 29th, and asked if the author considered the filters fully matured after this period. He questioned the author as to the rate of secondary filtration which would be necessary to bring the filter effluent within the 20 p.p.m. standard required by the West Riding Rivers Board. Dr. Goldthorpe stated the preliminary period was given over to experimental work, largely with distributors, and that the filters had apparently matured in about three weeks. He hoped to be able to apply the rapid filter effluent to secondary filters at about twice conventional rates.

Mr. C. Lumb (Halifax) thought it would have been desirable to increase the flow through the rapid filters during wet weather to correspond to normal increase in plant flow. He wondered if Dr. Goldthorpe could explain the removal of three times the oxygen-demanding material per acre in the 20 m.g. filter which received only twice the dosage of the other. At Halifax they had forty filters dosed at a rate of 50 gallons per cu. yd. and he wondered if there would be actually much improvement obtained by putting all flow through one filter and then re-applying it to the other 39. Dr. Goldthorpe replied that he wanted to avoid another variable by keeping the flow constant but that a study of the 10 m.g. filter in dry weather as against the 20 m.g. filter in wet weather might partially answer the question. He thought the fly nuisance could be lessened by placing the rapid filter away from houses and that the secondary filter would probably have less film growths and fewer flies than in conventional operation.

Mr. T. Gough (Spenboro) brought out by questioning that the 2 in. to 4 in. medium had been so chosen as to be slightly larger, ½ in., than that generally used in American experiments.

Dr. A. Key (Leeds University) suggested that experiments made on the same rate of flow per cu. yd. of material as rapid filtration but at a rate per acre equivalent to conventional trickling filter practice (*i.e.*, filtration through a very shallow bed) might be interesting and would show whether a stated volume of medium could best be utilized in a shallow or deep layer, with rapid linear flow in either case. He suggested as possible reasons for the increased efficiency of rapid filtration: better ventilation, higher temperatures, especially in winter, or the deposition of sludge more uniformly throughout the bed.

Mr. D. H. Barraclough suggested that the increased removal of oxygen-demanding materials from the more concentrated sewage was due to supplying the filter with a greater amount of material which it was capable of removing. Because of the low overall removal, it seemed unlikely that the process would be adopted in England as a single-stage process.

Mr. W. D. Scouller (Huddersfield) mentioned work by the Royal Commission at rates up to 550 gals. per cu. yd. which gave trouble with filter clogging, and work by Dr. Mohlman treating sewage with a B.O.D. of 70 p.p.m. which gave a similar percentage purification to that at Huddersfield, about 50 per cent. He thought the oxygen absorbed figures for permanganate were high due to organic dye wastes which would absorb oxygen from permanganate but which were not amenable to biologic oxidation. He commented on the uniformity of the results obtained at Huddersfield as against Halvorson's results which showed a variation of from 30 to 80 per cent removal. He thought the higher temperature of the bed during cold weather had much to do with the success of the process. Additional experiments were being planned at Huddersfield with a filter 20 ft. in diameter, divided into two parts, with a different size medium on each part.

Mr. E. H. Staynes (Chairman) cited experiments at Dewsbury on double filtration, using two 6 in. diameter filters with 5 ft. of 1 in. hard clinker and 6 in. of 3 in hard clinker on the bottom. Settled sewage was fed at a rate of 400 gal. per cu. yd. to one filter and then passed through the second. After 6 weeks the first filter clogged with a grey slime which disappeared rapidly on reversing the order of dosage of the filters, and by again reversing the order of dosage every three weeks, clogging could be

avoided. An attempt to increase this rate to 500 gal. per cu. yd. had resulted in decreased efficiency of the primary filter. Results obtained were as follows:

		Oxygen absorbed (P.p.m.)	5-day B.O.D. (P.p.m.)	NO_3 (P.p.m.)	Per cent purification
First period, 6 weeks	Tank effluent	45.8			
	Primary filter	10.9	10.5	9.8	76.20
	Secondary filter	9.5	8.6	14.9	79.21
Second period, 3 weeks	Tank effluent	47.4			
	Primary filter	11.5	11.2	6.5	75.95
	Secondary filter	9.2	8.4	11.9	80.59
Third period, 3 weeks	Tank effluent	43.0			
	Primary filter	14.3	20.2	4.6	66.75
	Secondary filter	9.5	8.2	10.0	80.23
Fourth period, 3 weeks	Tank effluent	52.7			
	Primary filter	13.0	18.3	4.9	75.33
	Secondary filter	10.2	8.3	9.0	80.65

R. W. KEHR

MULTIPLE-STAGE SEWAGE SLUDGE DIGESTION

BY A. M. RAWN, A. PERRY BANTA AND RICHARD POMEROY

Proceedings, American Society of Civil Engineers, 9, 1673 (Feb., 1937)

This 26-page paper reports the results of four years' experience with multi-stage digestion in a full-sized plant at the Los Angeles (Calif.) County Sanitation District works near Harbor City. The whole plant has been treating 14–18 M.G.D. of sewage by the activated sludge process. Sludge has been digested satisfactorily in ten days.

Digestion Tanks.—A group of digestion tanks consists of four contiguous tanks, each 56 ft. wide, 37½ ft. long, 19 ft. total depth, and 15 ft. water depth. The tanks are arranged in a line with one wall common to two tanks and so that the top of each tank is three feet below that of the tank preceding. The bottom slopes continuously 1 on 12 with a sludge hopper at the lower end of each tank. Longitudinally, the tanks are divided into three equal bays by baffles which extend from the roof to within one foot of the bottom. Gas openings are provided in the baffles at roof line. Hot water piping in vertical loops supplies heat—chiefly to Tank No. 1. Gas is collected from domes in the roof.

Sludge—one-third primary, two-thirds activated, plus 20 per cent digested sludge—is introduced into the two outer bays of Stage 1 Tank. Sludge that sinks to the bottom passes under the baffles to the center bay from which it is piped to the two outer bays of Stage 2 Tank, where the process is repeated and so through all four tanks and stages. Thus the process is one of "gravimetric selection" wherein settling signifies inorganic material or—ultimately—the completion of digestion of organic material. Digested sludge is drawn from No. 4 Tank to a storage well for discharge to drying areas. Supernatant is taken from Tank 4 and occasionally from No. 3.

Sludge Quantities.—Total digestion data are given for quarterly periods. Two year averages of these are:

	July 1933 April 1935	July 1935 April 1937
Sewage Flow, M.G.D.	14.7	18.1
Raw Solids Added, Lb. per Day	46,700	—
Per Cent Volatile—Raw Solids	70.86	70.97
Digested Solids	56.59	55.57
Per Cent Digestion of Organic Matter	46.4	47.4
Average Moisture—Raw Sludge	95.3%	
Nominal Detention—days	13.5 to 10.3	

Actual Detention about 20 per cent less.

Scum.—Upon two occasions studies were made of the distribution and makeup of solids in the several stages. The first determination which followed 25 months of operation showed the greater percentage of the organic contents of the tanks to occur in the upper zones and covered with a thick scum mat. Samples of this scum were screened on an 8-mesh screen and were found to consist of about 17 per cent solids which were 62 per cent to 68 per cent organic material. The scum, despite much contained semi-permanent material, was quite digestible. Scum in this investigation was regarded as constituting about one-eighth of the tank solids. The total tank solids ranged from 9.4 per cent in Stage 1 to 2.7 per cent in Stage 4 with the volatile decreasing from 62.8 per cent to 58.1 per cent through the several stages.

The second survey of tank contents was made 7 weeks after a cleaning and showed no regularity in the vertical distribution of solids. The total tank solids varied irregularly among the four stages between 1.6 per cent and 3.5 per cent, but the volatile decreased with some uniformity in each stage from 64.1 per cent to 58.2 per cent of the solid material.

Reduction in Organic Matter.—The per cent organic matter destroyed is given by the formula,

$$\text{Per Cent Digested} = 1 - \frac{\text{Ratio of Organic to Ash in digested sludge}}{\text{Ratio of Organic to Ash in fresh solids}}$$

Over the four year period the organic matter added to the tanks was reduced by 47 per cent. Later detention for 27 days in the storage pits led to a 14 per cent reduction of the organic material added to the pit.

Gas—Production and Use.—Gas yields from the several stages of digestion were determined during four successive periods which aggregated 115 days. The gas measured and estimated as lost was 270,000 cu. ft. per day or 17,400 lb. gas from 16,300 lb. organic matter destroyed. This amount of gas is 107 per cent of the weight of organic matter destroyed. The average percentage production of gas from each stage was:

Stage 1—44.7% of total gas
2—21.2% of total gas
3—18.0% of total gas
4—16.1% of total gas

Additional digestion for periods of about 20 days served to increase the gas yield about 20 per cent. Digestion temperatures were from 79° F. to 85.6° F.

About 32 per cent of the gas was CO_2. Hydrogen sulfide rarely exceeded 0.02 per cent. About 50,000 cu. ft. of gas were burned daily and led to deterioration of flues in about eight months. This was eliminated by installing forced draft in the flues to prevent condensation.

Gas collection piping has not deteriorated, but electric conduits about the tanks have been affected by leakage of gas.

A 200 H.P. gas engine uses about 110,000 cu. ft. of gas daily. Power is produced at a cost of 0.18 per K.W.H. and to include operation, maintenance and 10 year amorti-

zation at 6% interest. Valves are ground 2–3 times yearly. Rings were changed after 23 months' operation.

Heating System.—The heating coils are 2-in. extra heavy W.I. pipe arranged vertically along the longitudinal baffles of the first three tanks. They were designed to raise the temperature of Tank 1 to 85 deg. and to compensate for losses in succeeding tanks. There is no temperature stratification. Clean pipe had a conductance of 347 B.t.u. per day per ft. of pipe per degree of temperature differential. After 30 months use with 0.5 in. scale coating, the conductance rate was 84 B.t.u.

Measurements of heat input led to the following:

Heat supplied in circulation water	13,900,000 B.t.u./day
Required for heating sludge in first stage	*13,400,000* B.t.u./day
Error, radiation and possible endothermic action in first stage	500,000 B.t.u./day
Heat input whole system	13,900,000 B.t.u./day
Sludge withdrawn	*12,700,000* B.t.u./day
Radiation and endothermic requirements 4 stages	1,200,000 B.t.u./day

The latter amount represents a value considerably less than that found by Keefer and Kratz.*

Foaming.—Foaming is observed occasionally in the first or second tanks but, only recently, has caused difficulty from stoppage of gas lines. Foaming is attributed to a temporary unbalance between fresh and digested sludge, and due, in turn, to periodic rather than more nearly continuous seeding. The first tank provides 6 ft. of height above the water line; the remaining tanks 4 feet.

Stirring.—Tanks are equipped with gas lifts for stirring, but their value or need is regarded as doubtful.

Sludge Drying.—Sludge is dried on sand beds—663 tons/Ac./yr. and also in lagoons 2 ft. deep—342 tons/Ac./yr. On the sand beds, with sludge at 4½ per cent solids, one-half of the moisture drains away in 48 hours.

Sludge is sold from the beds at $2.00 per ton of dry solids.

Costs.—Exclusive of land, the digestion tanks cost $132,000. Drying beds and lagoons cost $24,500. Annual costs for 1934 were:

	Digestion	Sludge Drying		Filtration Supernatant
		Sand Beds	Lagoons	
Operation and Maintenance	$ 3,455	$2,790	$ 545	$ 495
Capital Charges	10,580	1,480	250	260
Total	$14,035	$4,270	$ 795	$ 755
Sludge, Tons—Raw	8,470	2,730	5,740	6,770
Digested	4,800	1,550	3,250	3,840

Chemical Studies

The chemistry of digestion was studied in detail during a 12-month period. Half of the paper is devoted to this subject.

Changes in Sludge Liquor.—Analyses were run on the sludge liquor in the four stages and also on sludge digested for a subsequent period of 23 days. Determinations were made of solids, nitrogens, volatile acids, bicarbonate, silicon dioxide, phosphate, sulphate, chloride, calcium, etc. Principal quantitative values were:

* The Interchange of Heat During Sludge Digestion. *This Journal*, 5, 3 (1933).

	Days Detention	Nitrogen		Bicarb. HCO_3 *	Volatile Acids as Acetic	pH
		NH_3	Organic			
Sewage		22	8	—	26	
Seed Sludge		753	116	—	177	
Mixture		183 *	32 *	1306 *	59 *	
Stage 1	2.6	444	148	2124	829	6.74
2	2.6	583	93	3059	790	6.93
3	2.7	692	64	3929	470	7.06
4	1.3	757	77	4502	228	7.14
Post Digestion	23.	1026	113	5867	57	7.26

Except for pH, results are in parts per million.
* Computed.

The paper includes comments upon these and other determinations.

Digestion of Ether Soluble Matter.—Determinations for ether soluble matter showed averages of

Primary Sludge	18.2%
Activated Sludge	20.3
Digested Sludge	9.1
Pit Sand Sludge (post digested)	7.6

Subdivision of the ether soluble was:

	Primary	Activated	Digested
Free Acids	66%	62%	26%
Saponifiable fats	28%	20%	28%
Non-Saponifiable	6%	18%	46%
Phosphine (PH_3)	0.11%	0.06%	0.07%
Equivalent weight of acids	306	309	272

Comment is, the indications being, that "very little true fatty acids are present in the digested sludge, it appears that the insoluble soaps are destroyed quite completely in the digestion process."

Nitrogen Balance.—Determinations of nitrogen on samples of the different sludges showed no loss of nitrogen in the digestion process. This conclusion was later checked by careful experiment. A division of the nitrogen is shown by the following tabulation:

	Nitrogen in Solids	Nitrogen in Solution
Raw Sludge	98.6%	1.4%
Digested Sludge	56.8%	43.2%
Post Digested Sludge (23 days additional)	41.3%	58.7%

If the sludge is dried on sand beds to the usual 50 per cent moisture, it will contain about 60 per cent of the original nitrogen less that lost through digestion during drying.

The digestion of nitrogenous matter roughly parallels that of other organic matter and the percentage of nitrogen in solid matter shows no great change.

Changes in Solids.—Changes in solids are shown thus:

	Raw Sludge	Digested Sludge	Post Digested
Organic Matter	100	52.1	42.2
Soluble Matter	27.6	8.1	6.5
Protein *	36.2	21.2	16.1
Cellulose and Miscl.	36.2	22.8	19.6

Results in Pounds.

* Assumed at 6.25 × nitrogen percentage.

Gas Analyses.—Average values for determinations of gas content are quoted in the following table:

	First Stage	Fourth Stage	Lab.	Weighted Ave.
Carbon Dioxide	34.5	29.7	33.8	32.4
Hydrogen Sulphide	0.0068	0.0035	0.012	0.0043
Carbon Monoxide	0.03	0.02	—	0.03*
Hydrogen	0.018	0.01	—	0.02*
Oxygen	—	—	0.004	—
Phosphine	0.00001	0.00001	0.00001	—
Ammonia	—	0.00093	—	—
Methane (by difference)†	65.5	70.3	—	67.6

Results in per cent.

* Not to exceed values given.

† A sample analyzed for other hydrocarbons showed Ethane 0.04 per cent; Propane 0.01 per cent; Pentane and heavier 0.07 per cent.

Summary and Conclusions

The summary and conclusions of the paper are quoted verbatim:

"(1) Results of a 4-yr. study of the operation of a four-stage digestion system disclose that, with a nominal detention time of about 12 days, a reduction of 47 per cent of the organic matter added was achieved. The sludge produced dried satisfactorily without odor or fly nuisance, and showed no appreciable difference in drying characteristics when compared with sludge digested three times as long.

"(2) The results are also quite conclusive in determining that agitation by mechanical equipment is not needed in separate sludge digestion.

"(3) Controlled seeding of raw solids with digested sludge, as accomplished in the multi-stage process, may be a factor in efficient digestion.

"(4) The design of the tanks permitted a large accumulation of scum without reducing the efficiency of the system.

"(5) The survey reveals that no appreciable liberation or absorption of heat occurred during the digestion process.

"(6) The presence of relatively large quantities of iron salts in the sludge appears to have no deleterious effect upon the digestion process, and is beneficial in holding the concentration of hydrogen sulfide in the gas to a very low value.

"(7) No nitrogen is lost in the digestion process. A portion is converted into soluble form and appears in the sludge liquor. The quantity remaining in the solids is approximately proportional to the organic matter remaining.

"(8) The gas from the first stage is not substantially inferior to gas from the other stages as regards utilization for fuel; 47 per cent of all gas was produced in the first stage.

Frank C. Tolles

DISCUSSION

Proceedings, American Society of Civil Engineers, **64**, 596 (March 1938)

By Willem Rudolfs and H. Heukelekian

The method of selective withdrawal of solids is theoretically correct but unless sludge is circulated, the practice results in large and accumulating amounts of scum in the early stages. Data of the paper are interpreted to show that, when cleaned, Tanks 1, 2 and 3 had lost 25 to 30 per cent of their capacity.

Los Angeles sludge, as a mixture of 1/3 primary to 2/3 activated, is reported to have a solids concentration of 4.7 per cent. This high concentration may account in part for the short digestion periods. Operation data indicate that the tanks were working at full or even abnormal capacities.

Short time digestion has been attained elsewhere, but, in the absence of post storage and digestion, there has been difficulty in obtaining a free draining sludge which would dry under usual climatic conditions.

Temperature stratification may occur in a single tank where large amounts of digested sludge are held, but it should not occur in stage digestion. The drainability of sludge on drying beds is a function of the digestion. "Well-digested sludge (52 per cent solids) loses as much as 85 per cent of its total moisture (at 74° F.) by drainage." This decreases as digestion is less nearly complete, and at the point where 80 per cent of the gas has been evolved, reduction of moisture by drainage may be 40 to 50 per cent in the first 24 hours.

The fact that digestion entails no loss of nitrogen has been proved by other investigators. The nitrogen is transformed from insoluble to soluble and it is carried out with the supernatant. Soluble nitrogen also drains from drying sludge. If this could be retained it would constitute soluble nitrogen which would increase the fertilizer value of dried sludge. This has been accomplished in part in some processes.

Temperature is the important factor in the digestion of properly seeded sludge. Short period digestion at high temperature is effective in reducing solids, but the sludge does not dewater readily. Thermophilic digestion at 130° F. followed by digestion at 85° F. is practicable but necessitates stirring. The work at Los Angeles is valuable in showing the apparent practicability of short period multi-stage digestion which does not require excessive care in operation.

By Hermann Bach

The subdivision of a process into parts for more effective operation must include consideration of construction and operating costs so necessitated. The Los Angeles design by its inclusion of four stages into one structure, and in a manner that avoids undue increase for labor, minimizes such costs.

Question is raised as to the most desirable number of stages and as to whether there should be variations in sizes of compartments. Using gas production as an index of the progress of digestion, the following relations appear:

	Stages			
	1	2	3	4
Ratios of Gas Production	1	0.46	0.40	0.36
Ratios of Volume Requirements for equal gas production	1	2.1	2.48	2.8

The curve of digestion shows sudden decrease after substantial decomposition and then gradual reduction to a point which is beyond the "technical digestion range" (Imhoff). This characteristic of digestion must be recognized in determining the number of stages

and the volume for each. The reported data show nearly uniform rate of digestion in Stages 3 and 4 and suggests that it might be sufficient to provide three stages only if the third stage tank has more volume than the other two. This procedure would reduce the extent of "gravimetric selection" and this might prove to be the critical factor.

Scum is formed by the floating of fats and oils and, although mineral oils are very resistant to bacterial decomposition, those of animal and vegetable origin are susceptible to anaerobic action. The conditions of moisture and atmospheric isolation favorable to anaerobic activity are not met in the Los Angeles design where the scum is too dry. Means for moistening and for preventing atmospheric contact are needed.

The drainability of the sludge could be improved by providing for gravity discharge on to the drying beds instead of pumping as the latter releases entrained gas.

A number of corrections to the original article are given in the March *Proceedings*.

FRANK C. TOLLES

THE DESIGN AND OPERATION OF THE COLESHILL SEWAGE-DISPOSAL WORKS OF THE BIRMINGHAM, TAME AND REA DISTRICT DRAINAGE BOARD

BY FRANK CHARLES VOKES

J. Inst. C. E., Jan. 1938, pp. 323–362

The Coleshill Works is an activated sludge plant designed for a population of 67,000, with a flow of 36 gallons per capita per 24 hours. The dry flow is 2.5 Imperial m.g.d., but the plant can treat 7.5 m.g.d., and provide storm water settlement for an additional 7.5 m.g.d. The present population is around 50,000. The layout is arranged for expansion to 335,000.

The plant consists of a bar screen with 3½ in. openings, hand cleaned; a detritus tank with three channels, one being used on dry flow at 1 ft.p.sec. velocity. The detritus tank is cleaned by an electrically operated dredger. The purification plant is arranged in three parallel lines, each consisting of a primary sedimentation tank, a pre-aeration tank, a secondary sedimentation tank, an aeration tank in three separate parallel bays and a separating tank.

Each of the three primary sedimentation tanks is 44 ft. in diameter, with the floor sloped at 30 degrees to a central well. The tanks are mechanically cleaned, with center feed and peripheral outflow. In the pre-aeration tanks, the sewage receives the excess sludge from the aeration plant for ½-hour aeration. The three secondary sedimentation tanks are rectangular, through-flow type, with from 11.7 to 8.6 hr. period. These are hand cleaned.

Each of the aeration tank units has three separate parallel sections, 20 ft. wide, 110 ft. long, with four lines of 6-in. diffusers set at the bottom of V-shaped troughs. By weirs at the outlet the period can be varied from 16.4 to 12.3 hr. The depth over the diffusers varies from 8.5 to 11.25 ft. Rotary air compressors of the crescent type with sliding blades are used.

Each of the three final separating tanks is 44 ft. in diameter with the floor sloped at 30 degrees to the center well, continuously mechanically cleaned. The tanks have a capacity of 4 hr. dry flow. When passing three times the dry flow the maximum upward rate of flow is 8.8 ft.p.hour.

The sludge is digested in eight parallel rectangular tanks, each 61.33 ft. long, 31.33 ft. wide and 16 ft. deep. Five are used as primary tanks, the digestion being completed in the secondary tanks. The total capacity provided is 3.25 cu. ft. per capita. The total retention time is approximately 12 weeks. The supernatant liquor is conveyed to the incoming raw sewage, four acres of sludge drying beds are provided, or 3½ persons per sq. yd. Sheet steel gas collectors float on sludge in the five primary tanks. The steel employed contains 0.35 to 0.5 per cent copper. The gas is piped to the power

house to run two 120 h.p. 4-cylinder vertical engines direct-connected to an 80 KW. generator. The engines can be run on fuel oil in an emergency. The exhaust gases heat the alkaline water from the secondary digestion tanks, which is circulated through the primary sludge digestion tanks.

The plant went into service in October, 1934. The strength of the sewage varies greatly through the 24 hr. of the day. A small amount of marl was fed to the aeration tanks to improve the settling qualities of the sludge. Table I shows a typical 24-hour result from 8 A.M. on Feb. 3 to 8 A.M. on Feb. 4, 1936.

TABLE I

	Parts per Million				
	Crude Sewage	Primary Sedimentation-tank Effluent	Pre-aeration Tank-effluent	Secondary Sedimentation-tank Effluent	Final Effluent
Suspended solids	177	56	110	28	trace
Free ammonia	32.6	31.9	31.2	25.1	28.7
Albuminoid ammonia	6.8	6.7	3.9	4.3	1.3
Chlorides (as chlorine)	72	80	76	56	60
Oxidized nitrogen	—	—	—	—	1.5
Oxygen absorbed in 4 hours at 80° F. from N/80 $KMnO_4$:					
(*a*) Sample containing solids in suspension	45.6	41.2	40	23.2	6.8
(*b*) Sample after 2 hours' quiescent sedimentation	32.8	33.2	28.8	20.8	6.4

The effect of pre-aeration is indicated by a typical analysis:

	Parts per million	
	Without Pre-aeration	With Pre-aeration
Albuminoid ammonia	4.8	4.0
Oxygen absorbed in 4 hours at 80° F. from N/80 $KMnO_4$	30.3	22.9
Biological oxygen-demand in 5 days	107.0	70.3

Several interesting charts show the monthly averages for 1½ years. The air has varied from 1.1 to 1.8 million cu. ft. per day. The flow treated has varied from 1.25 to 4.05 m.g.d. The detention period has varied in the aeration tanks from 5 to 15 hours, with the air varying from 0.4 to 1 cu. ft. per gal. The return sludge was approximately 720,000 gallons per 24 hours and the excess sludge passed to the pre-aeration tanks was 90,000 gallons per 24 hours. The horse power per m.g.d. of average sewage was 14.20, and per m.g.d. of dry flow 18.78. The sludge pumped from the primary settling tanks averages 93.8 per cent moisture, with solids containing 75 per cent organic matter. The sludge from the secondary settling tank averages 97.3 per cent moisture with solids having an organic content of 79.5 per cent. The digested sludge discharged to the drying beds contains 95.5 per cent moisture, and the solids contain 54.2 per cent organic matter. The gas yield was 0.78 cu. ft. per capita per 24 hours. The temperature in the primary digestion tanks was 69 degrees F. (varying from 64 to 74 degrees).

Details on costs are given, together with a comparison with the cost of construction and operation of the other Birmingham works.

Plant	Pop'n.	Construction Cost	Total Annual Cost	Annual Cost per	
				Cap.	M.G.
No. 1	235,000	$ 720,650	$ 75,335	$0.32	$22.04
No. 2	375,000	1,006,300	102,915	0.275	18.80
No. 3	470,000	1,725,000	124,775	0.265	18.24
No. 4	125,000	529,100	42,570	0.335	23.36
No. 5	100,000	574,280	44,935	0.44	31.00
Coleshill	67,000	206,140	27,865	0.41	30.62

Note: Costs are translated into U. S. dollars on basis of £1 = $5.00.

No. 1. Minworth. Bioflocculation Plant No. 1; bacteria beds with fixed spray jets.
No. 2. Minworth. Bio-flocculation Plant No. 2; bacteria beds with rectangular travelling distributors.
No. 3. Minworth. Bacteria beds with fixed spray jets.
No. 4. Minworth. Bacteria beds with rectangular travelling distributors.
No. 5. Yardley. Bacteria beds with rectangular travelling distributors.
No. 6. Coleshill. Activated sludge works.

In the discussion, Messrs. T. Peirson Frank, R. G. Herington, H. C. Whitehead, C. B. Townend, L. F. Mountfort, Dr. Calvert, W. T. Lockett, A. P. I. Cotterell, W. H. Hillier, M. F. G. Wilson and the author took part. Lockett contrasted this plant operating with a low air supply and long detention period, with Mogden, a relatively liberal air-supply and short detention period. Lockett advocates using more air, if economically possible, and short periods, to avoid certain operating difficulties. Lockett favors operating to pass a mixed liquor to the final settling tanks containing 50 per cent saturation dissolved oxygen, or to have 10 to 20 parts of nitric nitrogen in the final effluent. He contrasts the gas yield of 0.78 cu. ft. per capita per 24 hours with 1.0 at Mogden.

The author pointed out that Modgen has a dry weather flow of 50 gallons per capita per 24 hours with 290 p.p.m. suspended solids, whereas Coleshill has respectively 37.5 gallons and 170 p.p.m. The primary sludge at Coleshill had a grease content of 26 per cent. High temperatures for digestion were not considered necessary. The sludge was loaded to a depth of 18 or 20 in. on the beds, drying to 5 in. in from 6 to 10 months. It was desirable to have more than 1 sq. yd. per 3.5 persons.

LANGDON PEARSE

FILTER PRESSING OF SLUDGE

BY J. T. THOMPSON AND J. W. PROCTER

Abstract, *The Surveyor*, **93**, 235–236 (February 4, 1938). Discussion, *The Surveyor*, **93**, 285–289 (February 11, 1938)

Filter pressing, in spite of its abandonment in the past under unfavorable conditions, is still the best method of sludge treatment in many places. This is especially true if the sludge contains sufficient grease to make recovery profitable after acidification or if the sewage contains trade waste which has a beneficial coagulating or sterilizing effect on the resultant sludge, or if the site available for sludge disposal is limited.

The capital cost for the new Leeds press house was about $210,000 for a plant including four air compressors, eight rams and 20 presses. The operating expenses* for the year ending March 31, 1937, were as follows:

* Note: Costs are translated into U. S. dollars on basis of £1 = $5.00.

Wages	$15,268
Lime (1,522 tons)	9,060
Jute cloth (29,920 yds.)	7,624
Cotton cloth (25,164 yds.)	2,359
Stores and coke	1,781
Proportion of power costs	2,628
Track repairs	93
Total	$38,813

During the year 131,900 tons of 90 per cent sludge were filtered, producing 36,780 tons of approximately 60 per cent cake. Therefore, excluding interest and sinking fund charges, operating costs were $1.05 per ton of cake, or $0.29 per ton of 90 per cent sludge. Other available figures on sludge disposal are: $0.99 per ton of pressed cake at Glasgow, compared to an estimated equivalent cost of $0.78 for barging the sludge to sea; $1.91 per ton at Burnley, where only 4,000 tons per year are produced in an old plant; in 1923 Watson gave figures of $0.31 per cu. yd. for digestion and air drying 90 per cent sludge on beds, which would amount to $0.29 per ton excluding interest, the same as filter pressing at Leeds.

To prevent fouling of the filter cloths due to fermentation during warm weather, the sludge is treated with 6 p.p.m. of chlorine, which is only about ¼ of the chlorine demand but it has proven beneficial in reducing odors and controlling fermentation. Lime (1 per cent) is added to make the sludge alkaline to phenolphthalein, and the sludge is allowed to remain for 48 hours for completion of the coagulation in the sludge hoppers of 400 tons capacity. Water is decanted carefully at each step and the normal water content of sludge going to the filters is 87 per cent, while that of the press cake averages 57 per cent.

Since the best cake is obtained by keeping the pressure low during the early stages of pressing, the feed lines to the lines of presses have been cross connected and one compressor is used to fill two lines (8 presses), the pressure being increased to a maximum during the last half hour of the run. Three hours are required to fill and press, and one hour for unloading, cleaning, etc., giving two pressings per day from each unit. The presses discharge directly into cars which are drawn by tractor up a runway and discharged either into railway cars or trucks. At present only 8 per cent of the cake is sent by rail, about 24,000 tons being sold at 25 cents per ton to farmers during 1937. Air-drying on a platform to 20 per cent moisture for disintegration and sale at $1.87 per ton was tried but the demand was small. The most economical filter cloth has been found to be a heavy twilled jute, 54 in. wide, weighing 30 oz. per sq. yd. and protected against fouling during warm weather by a 0.36 lb. cotton cloth. The cotton cloth tears away after about 30 fillings and the jute is then continued in service for another 30 fillings or so.

To determine the filtering quality of the sludge, it is experimentally conditioned and allowed to stand for 24 hours, then 300 c.c. is placed in each of several Buchner funnels with No. 3 Whatman filter paper. A regulated vacuum is applied and the time required for the vacuum to break due to cracking of the cake is multiplied by 5 to determine the approximate time required to form a good cake in the presses. Residues of thin sludge are digested for about 9 weeks in two 92,000-gallon tanks and can be pressed satisfactorily with the fresh sludge in concentrations up to 10 per cent.

Levels in the sludge storage tank are placed so that the upper half of the sludge flows by gravity to the rams while the lower half is drawn in by suction from the air compressors. One pair of rams is therefore emptied while another is filling. A working unit of the plant as a whole consists of one air compressor, one pair of rams and a line of four presses. Corrosion conditions in the plant are severe, requiring frequent protective painting and ample ventilation. The press plates are cleaned after drying with a rotating wire brush driven by an electric breast drill.

Discussion

Mr. C. Lumb (Halifax) commented on the development of sludge pressing in England as against vacuum filtration in America. He thought conditions were quite favor-

able at Leeds for filter pressing, since the lime required was comparatively small, the disposal of the cake to farmers fortunate and labor costs low due to the large size of plant. Acid pressing, while feasible largely due to grease recovery, yielded about 1/3 less cake due to a lower water content and the absence of a heavy precipitate from the added conditioner. By using heat, experimentally, they had obtained a cake of 33 per cent moisture.

Dr. H. H. Goldthorpe (Huddersfield) stated that the whole costs for acid pressing at Huddersfield were $5.00 per dried ton on 5,000 tons per year, but the income amounted to about $40,000. Pressing costs were $3.90 per dried ton, of which $1.52 was for acid. Their figures for the year were:

Wages	$ 6,195
Acid for pressing	6,700
Press cloths (5,000 sq. yd.)	2,000
Maintenance and repair	650
Materials	1,215
Power	805
Sundries	485
Total	$18,050

Excess liquor could not be decanted due to rising gas bubbles. The presses at Leeds seemed light, since his presses weighed 35 tons for a working pressure of 80 lb. as against 20 tons for a working pressure of 100 lb. at Leeds. In determining the filtering characteristics of a sludge in the laboratory, he had obtained more uniform results by using the time required for filtration of a definite volume of sludge liquor rather than the authors' method of timing the cracking of the cake.

Mr. F. Oliver (Harrogate) stated that he had improved filterability by using ochre water from a nearby mine in addition to lime as a coagulant. Heating the sludge had not improved its filtering qualities. He had found increasing the pressure to a maximum of 100 lb. per sq. in. during the first 40 minutes the equal of starting with a pressure of 40 lb. and gradually increasing it, but considered careful decanting of the excess water, pressing the sludge as fresh as possible and frequent cleaning of the press plates of more importance.

Mr. W. H. E. Makepeace (Hanley) stated that operating costs at Hanley were slightly higher ($1.26) than at Leeds, due largely to a bonus of $2.50 per week given laborers in that department.

Mr. T. Gough (Spenborough) described the method of sludge disposal in use at Spenborough. After abandoning, in 1915, a pressing scheme adopted in 1908, 22 acres of land were divided up into half-acre beds by 3½ foot earthen dykes. Sludge was pumped to these beds and, after digestion, a crust formed and eventually grew up with weeds and moss. Filling now took place under this seal and the level dropped from 1½ to 2 feet by evaporation and seepage between fillings. The sludge would, of course, have to be cleaned out at some time but so far this had not been necessary.

Dr. A. Key (Leeds Univ.) wondered if equally good results in filtering might not be obtained by adding the lime required for conditioning to the influent sewage. He also commented regarding the loss of soluble ammonia through lime treatment and stated that it might be worth while to study means of improving the fertilizing value of the sludge by retaining this ammonia.

Mr. E. H. Arrowsmith (Bredbury and Romiley) thought that recovery of power from digester gas should be weighed against the cost of sludge pressing.

Mr. P. G. Lloyd (Kingston on Thames) stated that pressing costs were only slightly higher at Kingston ($1.15) with a much older plant than at Leeds. At Kingston, however, they had capitalized the lime bill and put down extra presses, drawing sludge only once a day.

Mr. A. Hunter (Glasgow) mentioned difficulties they had had in disposing of the cake and that they had adopted barging the sludge to sea as the most economical overall method of disposal.

In reply to the discussion, Mr. Procter stressed the provision of convenient facilities for loading trucks with pressed sludge. The cake not disposed of to farmers was dumped about a mile from the plant at a cost of 25 cents per ton. Plate breakage at Leeds was minimized by casting eight small bosses, about 3 in. in diameter on each plate surface. He considered the life of press cloth to be a factor of rot rather than of strain from high pressure.

Mr. Thompson, replying to questions of a chemical nature, stated that they had used ferric sulfate waste to produce a good cake from stale sludge. There was very little ammonia in the sludge to lose and the chief value of the sludge as a fertilizer consisted of its humus content which slowly improved the condition of the soil. Mixing of digested and fresh sludge did not cause fermentation of the fresh sludge due to the short time elapsing before its disposal.

R. W. KEHR.

STABILIZATION OF SEWAGE SLUDGE BANKS

BY WILLEM RUDOLFS

Industrial and Engineering Chemistry, **30**, 337–340 (March, 1938)

Experiments were performed on the rate of stabilization of fresh sewage solids and activated sludge during storage, in an effort to determine the degree and duration of the effect of sludge banks on the overlying water.

The sludge was comminuted, screened, diluted with sewage and allowed to ferment one week before the experiment. Then the sludge was placed in two carboys, each two-thirds full. One carboy was stored open, and small evaporation losses were made up with water. In the other, the supernatant liquor above the sludge was replaced at intervals with tap water. B.O.D.,* total solids, ash and pH determinations were made at intervals on the mixtures and liquid discharged.

TABLE I.—*B.O.D. Reduction and B.O.D. per Gram of Volatile Matter Present*

Days	B.O.D.							
	Open Carboy			Decanted Sludge Carboy				
	Sludge			Sludge			Liquid Discharged	
	P.p.m.	Per Cent Reduced	Grams per Gram Volatile Matter	P.p.m.	Per Cent Reduced	Grams per Gram Volatile Matter	P.p.m.	Grams per Gram Volatile Matter
0	7060	—	0.537	7000	—	0.526	—	—
10	6180	12.5	.470	5550	20.6	.418	1700	1.51
18	7480	+5.0	.445	5860	16.2	.420	1775	1.28
38	6200	12.5	.382	5720	18.5	.426	730	1.52
111	3860	45.2	.280	2400	65.3	.240	180	0.51
129	1475	79.0	.251	1295	81.5	.210	115	.27
159	1075	84.8	.237	800	86.0	.187	60	.23
175	955	86.5	.217	655	89.3	.180	52	.22
209	520	93.4	.180	515	92.6	.163	46	.17
344	425	94.0	.110	430	93.4	.104	10	.08
401	440	93.8	.100	400	94.6	.104	3.5	.04

* All B.O.D. results are for 5 days at 20° C.

Fresh Solids.—The B.O.D. of the sludge in the open carboy dropped rapidly from 7,000 p.p.m to 1,500 in 130 days, and to slightly over 500 in 200 days. Thereafter the reduction was very slow. The B.O.D. of the sludge from which the liquid was decanted periodically was reduced more rapidly during the first 100 days, but thereafter the reduction was similar to the open carboy sludge. The results over a period of 400 days are shown in Table I.

The rather resistant volatile matter left in the sludge after 400 days had a B.O.D. of 0.1 gram per gram volatile matter, or roughly about 20 per cent of the B.O.D. per gram volatile matter of the original fresh solids. After 100 days, the discharged liquor had a B.O.D. comparable to an average domestic sewage. After 10 days, the B.O.D. per gram volatile matter in the liquid (1.51) was about three times as great as in the sludge (0.418). The B.O.D. per gram volatile matter in the liquid changed gradually and became the same as in the sludge after about 200 days. Finally the B.O.D. of the supernatant became very low, the same as found in many streams. This indicated that the putrescible matter in the sludge disintegrated, liquefied and passed into the overlying water in proportion to the quantity originally present.

TABLE II.—*Volatile Matter Reduction and pH Values*

Days	Open Carboy		Decanted Sludge	
	pH	Per Cent Volatile Matter Reduced	pH	Per Cent Volatile Matter Reduced
1	4.8	1.314*	4.8	1.820*
111	3.5	47.3	3.6	47.8
159	7.5	65.0	7.1	53.0
209	8.3	66.4	7.0	58.2
401	8.6	68.8	7.3	63.7

* Original concentration.

The volatile matter reduction results and pH changes in this experiment are shown in Table II. These data indicate that (after the pH has reached a minimum) there is a reciprocal relationship between the B.O.D. reduction and the pH of the sludge and that the pH value indicates the relative stabilization of the material. At the end of the experiment dissolved oxygen was present in the supernatant of the decanted sludge, small quantities of ammonia remained and the liquor was clear, while in the open carboy the supernatant contained large quantities of ammonia but no dissolved oxygen and was still turbid with a brownish color.

Activated Sludge.—Two activated sludges, one from Tenafly and the other from Madison-Chatham, were placed in two open carboys. The rate of B.O.D. reduction was very rapid during the first 2 to 4 weeks. This was followed by a brief interval of little or no reduction and another period of rather rapid reduction which gradually decreased. These two sludges had initial B.O.D. values of 4350 and 2860 p.p.m respectively and, in 80 days, more than a 66 per cent reduction had been accomplished. After 170 days the B.O.D. of the Tenafly sludge was reduced to 450 p.p.m. and the Madison-Chatham sludge to 283 p.p.m.; then the rates of reduction decreased so that in 390 days the values were 213 and 218 respectively. While the results show that the time required to reach a certain B.O.D. level is shorter for activated sludge, calculations indicate that on a volatile matter basis there is a fairly direct relation between the B.O.D. of the different sludges and the time required for stabilization.

These experiments show that a mass of sludge deposited in the stream affects the B.O.D. of the water passing over it to the greatest extent during the first weeks. When sludge is deposited continuously, the effect of a given quantity of sludge is rather

constant on the river. Temperature greatly influences the rate of decomposition, so that sludge deposited in cold weather would have considerably less effect on the water than when the water temperature is higher. In rivers and harbors receiving sewage solids continuously where only small quantities are removed by freshets or tides, the residue exerts a continuous effect. After one year, only a small fraction of the effect of the freshly deposited material is exerted. Where the sewage is removed from the watercourse, the river should rapidly improve, but the old sludge will exert a small but definite influence on the condition of the water.

C. C. RUCHHOFT

SURVEY OF THE RIVER TEES PART III. THE NON-TIDAL REACHES—CHEMICAL AND BIOLOGICAL

BY R. W. BUTCHER, J. LONGWELL AND F. T. K. PENTELOW

Water Pollution Research Technical Paper No. 6, Dept. Scientific and Industrial Research, XIII + 189, London, 1937

This is an excellent paper in twenty sections and two appendices dealing with the non-tidal section (75 miles) of a small, swift river which gets but little pollution itself, but whose principal tributary, the Skerne, is heavily polluted by sewage of the 72,000 inhabitants of Darlington. A portion of its 800 square mile drainage basin lies within the tidal zone, but just above this zone its flow averages from 100 m.g.d. in summer to 300 m.g.d. in winter. There is so little industrial pollution in the non-tidal area as to be negligible and the study can be considered one dealing with sewage pollution alone.

Geographic features of the river, industrial surveys, total sewage effluent data and rainfall data are well covered, giving an excellent background for the survey. Twenty-four sampling stations were set up and the river studied for four years.

Chemical Studies.—Detailed chemical investigations were made showing the mineral salts in the Tees and Skerne, while the range of free and saline ammonia, albuminoid ammonia, nitrous, nitric and organic nitrogen, dissolved oxygen, oxygen from acid and alkaline permanganate were ascertained. The five day B.O.D. was determined for the river water at various stations, as well as the B.O.D. of Darlington sewage, which averaged about 0.186 lbs. oxygen per day per inhabitant, about normal for domestic sewage. Using the B.O.D. of the various sewages, the B.O.D. of the river water above each sewer outfall and the estimated flows at these points, it was estimated that all sewage effluents except that of Darlington were sufficiently diluted by the river water, and concentrated work was done on the effect of this sewage on the Skerne and Tees.

The pollution shown chemically was substantiated by bacteriological tests. Numbers of bacteria above the mouth of the Skerne were small, but in the Skerne below Darlington, and in the Tees below the Skerne were large, and B. coli were usual in 0.01 ml. samples in these lower areas. The breakdown of organic nitrogen to nitrates as followed at eight stations indicated that bacterial decomposition of sewage in the Tees occurs quickly in the summer, but slowly in the winter. An interesting point is the observation that organic nitrogen may be due to plant remains in peaty water (or manure), which observation was supported by laboratory experiments. Peaty water is shown to have an organic composition increasing with the color, and besides introducing additional variables in the explanation of nitrogen relationships, it can cause clogging of filters in water treatment plants.

Self purification was shown to take place in three probable stages: (1) Development of bacteria and decomposition of complex organic substances with the production of ammonia compounds; (2) reduction of bacteria, increase of protozoa and the production of large quantities of nitrite; (3) production of nitrite and general formation of simple oxidation products. Confirmatory data for this were: (1) the average number of saprophytic bacteria (those growing on agar at 20° C.) passing a given station per minute, high at 20° C., very low up to 8° C., (2) their higher numbers at lower stations in winter than in summer, (3) greater concentration of dissolved oxygen at lower stations in summer than in winter, (4) lack of seasonal variation in B.O.D.

Botanical Studies.—One important series of observations showed marked diurnal variations in dissolved oxygen and correlated variations in pH and alkalinity. These were made by comparing stations with good growths of the green alga *Cladophora* and those where no *Cladophora* was present. It was further shown that the change in alkalinity was due to the conversion of bicarbonate to carbonate, due to the CO_2 demand. Another important observation was that supersaturation with oxygen did not occur because of physical factors as plunging over waterfalls, but only because of photosynthetic activities. A third observation was that photosynthetic activities and rate of decomposition of nitrogenous compounds were independent of each other.

The survey included the species of large aquatic plants and the areas they occupied. It was shown that they tended to stabilize the river bed and to increase the fertility of the river for other plants and animals.

Efforts were made to find the factors determining the heavy growths of the branching green alga *Cladophora*. Its seasonal distribution and its preference for sewage polluted areas was shown, but the actual heavy growth factor was not determined.

An important part of the survey and one on which very little work has been done elsewhere, was a study of the attached microscopic plants. These were investigated by allowing them to grow on slides hung in the water at various stations. In this way comparable counts were obtained, in numbers per square millimeter, and tables showing spatial and temporal distribution are given. The list is long, and includes: Diatoms, filamentous green algae, disc or plate forming (thalloid) green algae, blue green algae as well as some desmids and minute green algae normally belonging to plankton. Usual seasonal blooms of some of these algae were noted, as might be expected. But other factors were studied also, as current, floods, temperature, light and dissolved salts. Numbers were roughly proportional to the strength of the current. Floods generally reduced the numbers, but at least one species was most abundant at flood times. Scouring generally lasts but a short time but decreased illumination due to turbidity may last a long time following floods. Attention is called to the diverse effects of light and temperature on the growth of algae. Tentative conclusions regarding the factors favoring sessile algae are: (1) Four species favor water with a low concentration of dissolved salts. (2) Six species favor moderate salt and organic matter concentration. (3) Seven species favor a rich supply of these two. (4) Five species appear to require a high concentration of calcium salts.

Perhaps the most valuable contribution of this section is the abundance of carefully compiled data made available as a basis for further studies of this type.

The algal plankton was studied quantitatively and qualitatively. The amount was small because of the steep gradient of the river and the shortage of the water. Two conclusions are useful, however—that the plankton is largely derived from the sessile forms, being but little affected by that of reservoirs; and that observations on the plankton as an indication of river conditions are not so valuable as observations on the sessile forms. Whether these observations can be applied to rivers other than the Tees is a matter for investigation.

A valuable three year survey was made of the distribution and abundance of *Sphaerotilus* in the river. It showed that growth was inhibited by salt water and by colliery (sulfuric acid?) wastes but that oxygen concentration and usual temperature ranges affected it but little; the extension of its growth in winter being due to winter extension of the sewage polluted zone.

Zoological Studies.—It is pointed out that the larger animals of rivers have attracted little attention, at least as far as their relationship to pollution is concerned. Details of careful sampling show that the Tees was carefully studied. A complete list of the animals is given, although species identification of many is an impossible task, especially in field work. The largest group consists of insects. Communities rather than individual species are found to characterize environmental various conditions. Of extreme importance is the demonstration that some seven or eight genera make up the bulk of the animals at the four stations. This shows that instead of studying the whole animal kingdom for an indication of the condition of a body of water, a student could specialize on a relatively few groups characterizing particular zones. A striking illustration of this is the large number of tubificid worms which immediately make their

appearance in the Tees on the entrance of the sewage laden Skerne water. Five chief factors affecting animals are recognized; chemical composition, current, nature of the river bed, occurrence of large vegetation and pollution, and not one of these but is easily profoundly modified by man. The effect of pollution is shown in detail and valuable data given on the five groups of pollution loving animals headed by tubificid worms. The usefulness of this section is further enhanced by the detailed studies of the animals of non-polluted stretches, and by the data on seasonal variation of the commonly occurring animals.

Fisheries.—General observations are given showing that the Tees is a good river for several species of fish and that even in the polluted section just below the mouth of the Skerne, fishes at least survive to pass through. Brown trout and salmon were shown to be of commercial importance and the probability is advanced that if present pollution were curbed to a greater extent the river in all reaches might again become a good fishing river. Laboratory experiments were conducted to show that fresh sewage contains unstable oxidizable substances toxic to fish in as short a period as two hours, but 10 per cent sewage in tap water between 7° and 15° C. and with not less than 70 per cent oxygen saturation was not toxic to brown trout. Other experiments showed that sulfide of anaerobic sewage decomposition was a direct poison (regardless of asphyxiation) in as little as 3 p.p.m.

Studies were also undertaken which showed the food of the Tees fishes corresponded with the animal and plant list, with insect larvae as the principal food.

Altogether this survey is of extreme importance in water pollution and sewage literature particularly because of its broad approach to the subject, its mass of data which makes it a valuable "background" paper, and its acquaintance with the literature. The reviewer feels that its careful approach to conclusions is commendable and if he regrets the omission of studies of the microscopic animals, it is with the understanding that a vast amount of work has been performed and put on record, and the realization that there are limits to the amount of work three men can do.

JAMES B. LACKEY

PROGRESS

in Sewage Treatment Equipment for 45 years!

P. F. T.

P. F. T. Equipment is accepted as standard today because men of vision started over 45 years ago to specialize in the development and building of sewage treatment equipment. That they have kept steadfastly on their course is evidenced by the constant flow of improvements P. F. T. has engineered, and by thousands of installations.

From the beginning, P. F. T. has extended its friendly cooperation to consulting engineers and municipal officials. P. F. T. engineers' experience, knowledge and ability to serve embraces installations of every size—from the largest cities to the smallest towns.

Among P. F. T. Equipments in wide favor today are P. F. T. Rotary Distributors, Floating Cover Digesters, Sprinkling Filter Plants, Flame Traps, Waste Gas Burners, Twin Tank Controls, Alternating Siphons, Dosing Tank Counters, Sludge Pumps and other accessory devices.

May we send you bulletins on any or all of the complete line of Specialized P. F. T. Sewage Treatment Equipments?

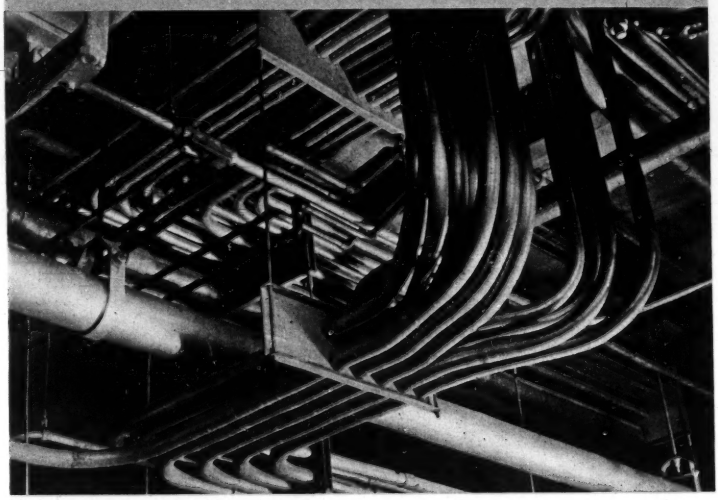
PACIFIC FLUSH-TANK COMPANY

4241 RAVENSWOOD AVE., CHICAGO, ILL.

NEW YORK - CHARLOTTE, N. C. - LOS ANGELES

IF IT'S CONDUIT YOU'RE BUYING (where Corrosion is a Problem)

specify Alcoa Aluminum Tubing



The electrical conduit shown above, in the blower building of a sewage disposal plant, is Alcoa Aluminum.

Six years ago, Alcoa Aluminum conduit was installed in an underground gallery at this sewage disposal plant. Today, although other piping and hangers in this same location appear to be in poor condition, the Aluminum is bright and undamaged by corrosion.

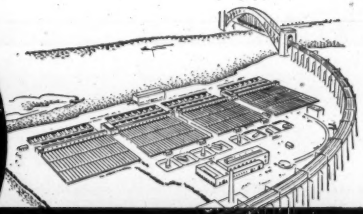
Appearances are an important factor in private as well as public properties. Equipment must have that well-cared-for look at all times. Aluminum, in addition to staying serviceable year after year under such corrosive conditions as these, retains its bright newness with a minimum of maintenance. That is why it pays to consider Aluminum wherever corrosion is a problem.

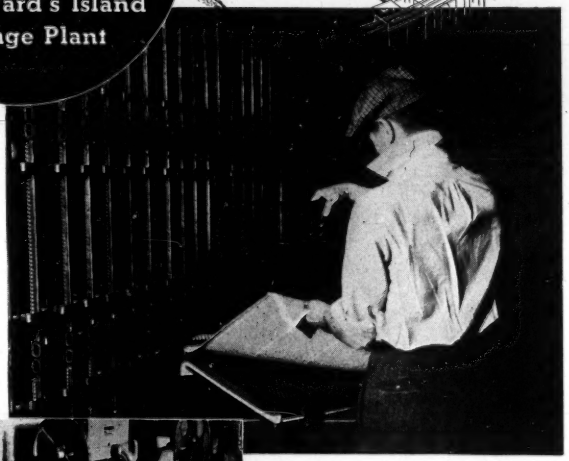
Alcoa Aluminum tubing is readily formed for the twists and turns required in conduit work. Its installation is no problem. May we quote you on your conduit requirements? Aluminum Company of America, 2111 Gulf Building, Pittsburgh, Pa.

★ ALCOA ★
ALUMINUM

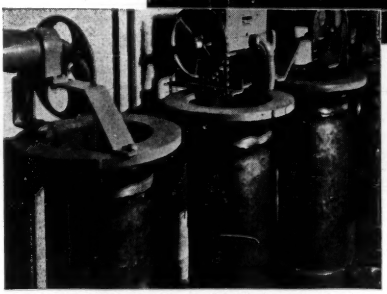
Everdur Metal

Selected on its Merit for Huge Ward's Island Sewage Plant





RIGHT—*Air-filter of secondary room. Framework of filter structure, holders and mesh are welded and bolted Everdur Sheet and Strip. Fabricated by American Filter Co., Inc.*



ABOVE — *Control mechanism of 12" diameter Everdur float tubes. Designed by Krajewski-Pesant Mfg. Corp.*

EVERDUR Copper-Silicon Alloy, selected for Ward's Island Sewage Disposal Plant, has an enviable record in the sewage, reservoir and water works field.

Since 1927 this Anaconda Metal, rustless as copper and steel-like in strength, has proved its dependability in the form of screens, gates, aprons, weirs, bolts, etc., under severely corrosive conditions.

It is readily workable, machinable and weldable, and its availability in all commercial forms makes possible the use of light-weight wrought shapes for built-up structures. Write for Publication E-11. 8822SA

Everdur Metal ANACONDA

THE AMERICAN BRASS CO. • General Offices: Waterbury, Conn.
Offices and Agencies in Principal Cities
In Canada: ANACONDA AMERICAN BRASS LTD., New Toronto, Ontario

"EVERDUR" is a trade-mark of The American Brass Company, registered in the United States Patent Office.

A PUMP THAT NEVER CLOGS

ASK FOR **"FLUSH-KLEEN"** BULLETIN 122

Requires No Attention

Impeller Handles WATER ONLY

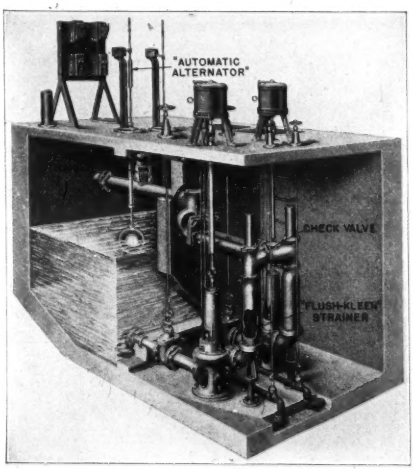


Fig. 2038—Duplex Open-Shaft "Flush-Kleen." Most reliable pump made for municipal sewage pumping stations. "Automatic Alternator" transfers operation from one pump to the other.

Keeps Solids From Basin and Pumps

Automatically Backwashes Strainer

CHICAGO PUMP COMPANY

VACUUM—CONDENSATION—CIRCULATING—BILGE
FIRE — HOUSE — SEWAGE — SCRU-PELLER PUMPS
AERATORS—COMMINUTORS—SAMPLERS

2314 Wolfram St., CHICAGO Phone: BRUnswick 4110

Gramercy Imhoff Tubes

Resistance glass; with uniform taper; designed for the more accurate determination of **Settleable Solids** in sewage. Capacity, 1 liter, graduated from 0 to 40 ml. in special subdivisions of increasing value from the tip.

OUR STOCKS INCLUDE COMPLETE LABORATORY APPARATUS FOR PHYSICAL AND CHEMICAL TESTING OF SEWAGE AND INDUSTRIAL WASTES.

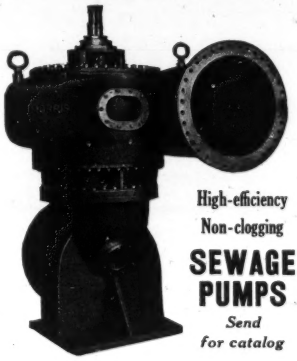
EIMER & AMEND

Est. 1851 Inc. 1897

Laboratory apparatus, chemicals and glassware for sewage disposal plants

205–223 Third Avenue, New York, N. Y.

MORRIS
CENTRIFUGAL PUMPS

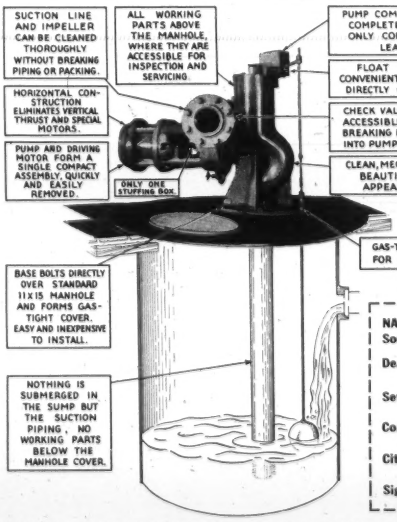


High-efficiency
Non-clogging

SEWAGE PUMPS

Send for catalog

MORRIS MACHINE WORKS
BALDWINSVILLE, N.Y.


SUCTION LINE AND IMPELLER CAN BE CLEANED THOROUGHLY WITHOUT BREAKING PIPING OR PACKING.
ALL WORKING PARTS ABOVE THE MANHOLE, WHERE THEY ARE ACCESSIBLE FOR INSPECTION AND SERVICING.
PUMP COMES WIRED COMPLETELY, YOU ONLY CONNECT THE LEADS.
FLOAT SWITCH CONVENIENTLY MOUNTED DIRECTLY ON PUMP.
HORIZONTAL CONSTRUCTION ELIMINATES VERTICAL THRUST AND SPECIAL MOTORS.
CHECK VALVE, READILY ACCESSIBLE WITHOUT BREAKING PIPING, BUILT INTO PUMP DISCHARGE.
PUMP AND DRIVING MOTOR FORM A SINGLE COMPACT ASSEMBLY, QUICKLY AND EASILY REMOVED.
ONLY ONE STUFFING BOX
CLEAN, MECHANICALLY BEAUTIFUL IN APPEARANCE.
GAS-TIGHT GUIDE FOR FLOAT ROD.
BASE BOLTS DIRECTLY OVER STANDARD 11'x15' MANHOLE AND FORMS GAS-TIGHT COVER. EASY AND INEXPENSIVE TO INSTALL.
NOTHING IS SUBMERGED IN THE SUMP BUT THE SUCTION PIPING, NO WORKING PARTS BELOW THE MANHOLE COVER.

JENNINGS SELF-PRIMING PEDESTAL TYPE SUCTION SUMP AND SEWAGE PUMP

(MAIL THIS COUPON TODAY)

NASH ENGINEERING CO.
South Norwalk, Conn.

Dear Sirs:

Please send complete illustrated Sump and Sewage Pump Bulletin.

Company_____

City_____ State_____

Signed by_____

NASH ENGINEERING COMPANY, South Norwalk, Connecticut

:: DIRECTORY OF ENGINEERS ::

FULLER & McCLINTOCK
ENGINEERS
F. G. Cunningham Ernest W. Whitlock
Elmer G. Manahan H. K. Gatley
Sewage Treatment, Sewers, Waterworks, Purification, Drainage, Waste Disposal, Valuations.
11 Park Place New York

NICHOLAS S. HILL ASSOCIATES
Consulting Engineers
Specializing in Sewerage and Sewage Disposal, Water Supply and Water Purification, Valuations and Reports.
Chemical and Biological Laboratories.
112 East 19th Street New York, N. Y.

GREELEY & HANSEN
Hydraulic and Sanitary Engineers
Investigations and Reports. Plans and Specifications. Supervision of Construction. Supervision of Operation.
Water Supply and Purification
Sewerage and Sewage Disposal
Garbage Collection and Disposal
Appraisals
6 North Michigan Avenue, Chicago, Ill.

MORRIS KNOWLES, Inc.
Engineers
Water Supply and Purification, Sewerage and Sewage Disposal, Valuations, Laboratory, City Planning.
Westinghouse Bldg. Pittsburgh, Pa.

BLACK & VEATCH
Consulting Engineers
4706 Broadway, Kansas City, Mo.
Sewerage, Sewage Disposal, Water Supply, Water Purification, Electric Lighting, Power Plants, Valuations, Special Investigations, Reports and Laboratory Service
E. B. BLACK N. T. VEATCH, JR. A. P. LEARNED H. F. LUTZ
F. M. VEATCH J. F. BROWN E. L. FILBY R. E. LAWRENCE

METCALF & EDDY
Engineers
Charles W. Sherman John P. Wentworth
Almon L. Fales Harrison P. Eddy, Jr.
Frank A. Marston Arthur L. Shaw
E. Sherman Chase
Water, Sewage, Drainage, Garbage and Industrial Wastes Problems
Laboratories Valuations
Boston, Mass. Harrisburg, Pa.
Statler Building Telegraph Building

ALBRIGHT & FRIEL, INC.
Engineers
Chester E. Albright Francis S. Friel
Water Supply and Purification
Sewerage and Sewage Disposal
Industrial Waste and Refuse Disposal
Investigations Valuations Reports
1520 Locust Street
Philadelphia, Penna.

John W. Alvord Louis R. Howson
Charles B. Burdick Donald H. Maxwell
ALVORD, BURDICK & HOWSON
Engineers
Water Works, Water Purification, Flood Relief, Sewerage, Sewage Disposal, Drainage, Appraisals, Power Generation
Civic Opera Building Chicago

GASCOIGNE & ASSOCIATES
Consulting Sanitary Engineers
G. B. Gascoigne A. A. Burger
W. L. Havens F. W. Jones
C. A. Emerson, Jr. F. C. Tolles
Water, Sewage, Garbage and Industrial Waste Problems—Valuations and Rate Investigations
CLEVELAND Leader Bldg. **NEW YORK CITY Woolworth Bldg.**

WHITMAN, REQUARDT AND SMITH
Engineers
Ezra B. Whitman Norman D. Kenney
Gustav J. Requardt Robert T. Regester
Benjamin L. Smith Theodore W. Hacker
WATER WORKS—SEWERAGE—UTILITIES
Baltimore, Md. Albany, N. Y.

Consulting
Hydraulic
Sanitary
ENGINEERS
Place your professional card in our DIRECTORY OF ENGINEERS
Ask for our card showing the advertising rates which are exceptionally low.
SEWAGE WORKS JOURNAL
654 Madison Ave. New York, N. Y.

TWO WORTHINGTON 90-HORSEPOWER GAS ENGINES
operating on sludge gas
at the City of La Crosse, Wisconsin
...a recent addition to a steadily growing list of successful
installations of Worthington Gas Engines in this service
WORTHINGTON GAS ENGINES
are convertible to fuel oil operation
for service during periods when
supply of sludge gas is low.
30 to 1800 horsepower
DIESEL ENGINES
25 to 1500 horsepower
COMPLETE PUMPING EQUIPMENT
OF ALL TYPES
CONDENSERS AND
ALL AUXILIARIES
AIR AND GAS COMPRESSORS
WORTHINGTON PUMP AND MACHINERY CORPORATION
General Offices: HARRISON, NEW JERSEY - Branch Offices and Representatives in Principal Cities throughout the World

ARE YOU PART OF THIS PROUD RECORD?

The American Public Health Association was established in 1872. It has grown steadily in power and influence because it has held the interest and loyalty of its members, as this table shows:

3	MEMBERS FOR OVER 50 YEARS
4	MEMBERS FOR 45 to 49 YEARS
5	MEMBERS FOR 40 to 44 YEARS
21	MEMBERS FOR 35 to 39 YEARS
32	MEMBERS FOR 30 to 34 YEARS
123	MEMBERS FOR 25 to 29 YEARS
303	MEMBERS FOR 20 to 24 YEARS
546	MEMBERS FOR 15 to 19 YEARS
779	MEMBERS FOR 10 to 14 YEARS
1082	MEMBERS FOR 5 to 9 YEARS
1901	MEMBERS FOR 1 to 4 YEARS
965	MEMBERS FOR LESS THAN 1 YEAR
5764	TOTAL MEMBERS AS OF MARCH 1, 1938

American Public Health Association

50 West 50th Street

New York, N. Y.

From Coast to Coast—It's a Royer for the Sludge

NOW Being USED by the Following

County Commission of Jefferson Co. Sanitary Department	Birmingham, Alabama
City of Durham	Durham, N. Carolina
City of Griffin	Griffin, Georgia
City of Los Angeles Sewage Dept.	Los Angeles, California
City of Reading, Sewage Disposal Plant	Reading, Pennsylvania
City of San Francisco	San Francisco, California
Coleman Disposal Company	Boston, Massachusetts
Dehydrating Process Company	South Boston, Mass.
Green Bay Metropolitan Sewerage District	Green Bay, Wisconsin
Peter Kiewit Sons Company	Denver, Colorado
Norwalk Sewage Treatment Plant	Norwalk, Ohio
Rahway Valley Joint Meeting	Rahway, N. J.
Soil Food Company	Hazlet, N. J.
Village of Freeport	Long Island, N. Y.
Village of Garden City, Department of Public Works	Garden City, N. Y.
Borough of Princeton	Princeton, New Jersey
City of Medford	Medford, Oregon
Sheboygan Treatment Plant	Sheboygan, Wisconsin
Paul Nagtegaal & Son	Sheboygan Falls, Wisconsin
Sewage Disposal Plant	De Pere, Wisconsin
Sewage Disposal Plant Harlem Valley State Hospital	Wingdale, New York
City of Dayton	Dayton, Ohio
City of New York	Coney Island Plant, Brooklyn, N. Y.
Town of Stratford	Stratford, Connecticut
Town of Tonawanda	Tonawanda, N. Y.

ROYER FOUNDRY & MACHINE CO.
KINGSTON, PA.

C. G. WIGLEY, *Sole Representative*
3108 Atlantic Avenue Atlantic City, N. J.

A ROYER PAYS FOR ITSELF

WE WILL PAY

Seventy-five cents for each of the first 25 copies of the following back numbers of SEWAGE WORKS JOURNAL sent to us:

January and May, 1932 - (Volume IV, Nos. 1 and 3)
January, 1934 - - - - - (Volume VI, No. 1)
May and July, 1935 - (Volume VII, Nos. 3 and 4)

SEWAGE WORKS JOURNAL
654 Madison Avenue
New York, N. Y.

"Taffy" TROUBLE

. . . is practically ended when you use liquid chlorine free from *hexachloroethane*

A single glance at that persistent, sticky gum known as "taffy," and it is easy to see what it does to a chlorinator. No accurate mechanism could continue to function properly with such a substance clogging up its parts.

Determined to clean up the Liquid Chlorine supplied to water works users, this Company has found that the most persistent trouble-maker is *hexachloroethane*. Remove that, and you've ended most "taffy" troubles originating from Liquid Chlorine quality.*

We have done just that. You can depend on this Liquid Chlorine to cut down chlorinator irregularities. This pure product is promptly available in any desired quantity. We will gladly quote on your requirements.

Liquid Chlorine

PENNSYLVANIA SALT MANUFACTURING CO. · Est. 1850
Widener Bldg., Philadelphia, Pa.
New York · Chicago · St. Louis · Pittsburgh · Tacoma · Wyandotte

PERCHLORON · CHLORINE · AMMONIA
FERRIC CHLORIDE · FILTER ALUM

PENNSYLVANIA SALT *Chemicals*

*"Taffy" in a chlorinator frequently is due to other things, such as over-lubrication of chlorinator parts in contact with chlorine, failure of oil chamber pressure gauge diaphragm, moisture entering chlorine chambers during shutdowns or changeovers, etc.

INDEX TO ADVERTISERS

	Page
Albright & Friel, Inc.	16
Aluminum Co. of America	12
Alvord, Burdick & Howson	16
American Brass Company, The	13
American Public Health Association	18
American Well Works	3
Black & Veatch	16
Carborundum Company, The	5
Cast Iron Pipe Research Assn.	10
Chain Belt Company	6
Chicago Pump Company	14
Dorr Company, Inc., The	2
S. R. Dresser Mfg. Co.	9
Eimer & Amend	15
Filtration Equipment Corp.	8
Fuller & McClintock	16
Gascoigne, George B., & Associates	16
Greeley and Hansen	16
Hill, Nicholas S., & Associates	16
Johns Manville Corp.	7
Knowles, Inc., Morris	16
Link-Belt Company	4
Metcalf & Eddy	16
Morris Machine Works	15
Nash Engineering Company	15
Pacific Flush-Tank Company	11
Pennsylvania Salt Mfg. Co.	20
Roger Foundry & Machine Co.	19
Wallace & Tiernan Company, Inc.	Back Cover
Whitman, Roquardt & Smith	16
Worthington Pump & Machinery Corp.	17

When writing these, please mention the

SEWAGE WORKS JOURNAL

LANCASTER PRESS, INC., LANCASTER, PA.

REAL VALUE FOR YOUR CHLORINATION DOLLAR

DEPENDABLE CHLORINATION
at seventy miles an hour . . .

SEVENTY miles an hour—one hundred and three feet per second—is the average water velocity through the injector throat of a W&T Chlorinator. To find a material which would withstand the erosive action of this constant high velocity, W&T engineers searched the market, made exhaustive tests, tried out every available material. Finally, they found it—a material equally resistant to the erosive action of the water and to the corrosive action of chlorine solution, a material which would last for years and yet one which could be machined with the high degree of accuracy required.

Remember—yes—this constant research, this high standard of the best material money can buy, this rigid supervision over every detail of design and manufacture, but the result is a great Chlorinator—an equipment we are proud to sell and you will be proud to own, an equipment designed and built to fulfill every requirement for the accurate, dependable control of chlorination.

The very nature of the task Chlorination has to do warrants the best equipment. When the choice is up to you, be sure you specify W&T—your reward will be constant dependability, unwavering accuracy and negligible maintenance expense.

Ask for Technical Publications describing W&T Chlorinators.

WALLACE & TIERNAN CO. INC.

Manufacturers of Chlorine and Ammonia Control Apparatus

NEWARK, N. J. Branches in Principal Cities

"The Only Safe Water is a Sterilized Water"

CHLORINATORS FOR WATER WORKS - SEWAGE PLANTS - SWIMMING POOLS - INDUSTRIAL PLANTS

8A-72